Cover: A group of men preparing to sink a shaft for the Canadian Copper Company, about the turn of the century. The site is at the south end of Cobalt Street in Copper Cliff, Ontario.

Photo courtesy of Inco, Ltd.

Report
of
The Ontario/Canada Task Force
for
The Development and Evaluation
of
Air Pollution Abatement Options
for
Inco Limited
and
Falconbridge Nickel Mines, Limited
in the
Regional Municipality of Sudbury, Ontario.

Fall, 1982

The Hon. K. C. Norton, Q.C.,
Minister,
Ministry of the
Environment,
Government of Ontario.

The Hon. J. Roberts,
Minister,
Department of the
Environment,
Government of Canada.

Dear Mr. Minister:

The Ontario/Canada Task Force on Inco Limited and Falconbridge Limited, established in May of 1980, is pleased to submit its final report.

In order to fulfill the Task Force's mandate, we have examined the smelting operations in Sudbury. Throughout our deliberations, we have focussed on the following factors:

- the industrial processes used now, as well as those used in the past;
- the environmental consequences of historic, current and projected emissions;
- the improvements in processes and the introduction of technologies that would further reduce airborne pollutant emissions;
- the financial review of various abatement programs;
- the socio-economic consequences of various emission reduction measures;
- the market outlook for the industries, projected over the next 20 years;
- the policy considerations associated with abatement implementation.

We were charged with the responsibility of identifying reasonable options for reducing emissions and for assessing the potential consequences of such reductions.

It is hoped that this analysis will be of assistance to those charged with the ultimate responsibility for implementation of the actual reduction in emissions. This report does not presume to establish government policy. It has attempted to suggest possible criteria that may guide the development of policy. Governmental response must be formulated by the authorities having appropriate jurisdiction, both for the regulation of the industries located in Sudbury and for the protection of the environment.

The conclusions of our work are presented in the form of a number of key questions and corresponding answers. Given the varied backgrounds and interests of the members of this Task Force, it would be surprising if all members agreed with the interpretation of every item of information contained in this report. However, we are unanimous in expressing the following conclusions.

> Question: "Is there, today, significant environmental damage occurring which results from the emissions of Sudbury's smelting and ore processing industries, and if so, can this damage be lessened?"
>
> Answer: The answer to this question is "yes" on both counts. Damage is occurring as a result of the emissions from Sudbury's smelting operations and the damage can be lessened with further reductions. In the area within 100 km of Sudbury, there are two problems. The first concern is the impact due to the deposition of metal particulates. Present levels of metallic particulate emissions are sustaining the widespread aquatic ecosystem damage. The current problem is made worse by historic metal contamination of the soils in the area. Therefore, it is difficult at this time to estimate the time scale for natural recovery of the affected Sudbury environment. However, there is no doubt that a reduction in metallic particulate emissions will begin to rectify the severe environmental stress which exists.
>
> The second problem within 100 km of Sudbury is due to the SO_2 emissions of the two Companies. These emissions aggravate the metal particulate problem and, as well, they significantly contribute to other types of ecosystem damage. However, SO_2 emissions from other sources beyond the Sudbury area are also at fault. Still, the contribution of Inco and Falconbridge within 100 km of Sudbury is larger than that from any other single source or from any other province or state in North America. Past emissions from Sudbury

have damaged the soils, forest cover and lakes. The capability of the ecosystem in this area to recover from this damage has been severely taxed. Due to reductions in emissions and other measures which have occurred during the past 15 years, the vegetation and forests within 100 km of Sudbury are now largely protected from short-term acute SO_2 damage. However, many of the lakes are either acidified or are still endangered by the current fallout of SO_2 and its derivative, acid rain. The environment around Sudbury would certainly benefit from any reduction in local sulphur dioxide emissions, but since the Sudbury environment is also impacted by sources a long distance away, the damage incurred as a result of these emissions would continue.

The environmental impact beyond 100 km from the Inco and Falconbridge operations varies, depending on the pollutant. Impacts from particulates beyond 100 km are not significant. There is a long distance impact from the sulphur dioxide emissions, but as one travels further away from Sudbury, the influence of Sudbury's industries relative to the total diminishes until, eventually, it becomes very small. It is not appropriate therefore to label Sudbury as the only "villain" in the long range transport phenomenon which produces "acid rain". Consequently, large reductions in sulphur dioxide emissions from Sudbury alone are not expected to have a significantly beneficial effect upon sensitive areas which are several hundred kilometers away. Recognition of this fact does not in any way diminish our conviction that "acid rain" must be reduced throughout eastern North America, and that any North American actions intended to reduce "acid rain" to acceptable levels must include effective abatement in Sudbury as an essential component. In other words, such abatement is justified on environmental grounds.

Based on these considerations, we have concluded that control of air pollutants from Inco and Falconbridge is necessary to protect the region within 100 km of Sudbury as well as to assist in lessening ecosystem harm at greater distances.

Question: "Is it practical to take effective action and reduce emissions within an acceptable time period?"

Answer: We agree that there are a number of effective, reliable technical abatement options available to both Inco and Falconbridge which can be installed within 3 to 12 years and which will significantly reduce emissions. We have reviewed the capability, cost and implementation times of some of the more promising options and are satisfied that, from among those examined (or others the Companies may prefer), both Inco and Falconbridge can find technical solutions that will meet their needs while at the same time achieving specified emission reductions. The cost of some options is large; however, benefits arising from increased productivity, sale of by-products and improved working conditions should offset the financial burden to some extent.

We have examined the costs of the programs but have not evaluated the full effect of these on the entire corporate entities. However, we note that each of these options will have effects on the individual Company's financial position. Some of these effects would result from changes in operating costs, the ability and need to raise funds (either internally or externally), the impact on cash flow and the degree of tax relief which may be available.

The impacts that such actions would have on the social and economic fabric of the Sudbury region have also been examined. The large cost abatement options themselves will offer short-term employment opportunities, but in the long run, will produce negative changes in the community. These changes are not large relative to the significant adverse effects which the community is experiencing as a result of current layoffs and shutdowns at the two smelters, but will nonetheless worsen the region's economic situation.

Question: "How can the government reconcile environmental needs and economic conditions, so that effective action results which is fair to the industries concerned?"

Answer: The present state of the world economy and the expected weak demand for nickel and associated metals dictate the necessity for caution, while the environmental requirements dictate that effective abatement of emissions begin at once. Both the extent of the cutbacks in emissions and the proposed timetable for the implementation of such cutbacks are therefore critically important matters.

From a technological viewpoint, action to reduce emissions could commence within the next one or two years. However, because of the current unfavourable condition of the world metal markets which is expected to persist for some time, substantial costs would have to be incurred at a time when the Companies are already under severe financial stress. Although projected future growth in metals demand is low and average prices are forecast to remain flat in real terms, a cyclical recovery from the current extremely depressed state should occur in the next few years, creating a more favourable climate for implementation of emission reductions. Thus, the picture may not be altogether bleak.

On the other hand, from an environmental viewpoint, damage caused by smelter emissions will continue until effective abatement is achieved. It is thus imperative, from the environmental perspective, for action to begin as soon as possible.

We recognize that many of the available process options which lead to emission reductions can be undertaken in stages. Therefore, we conclude that the planning and design of possible emission reduction measures available to both Companies should proceed as quickly as possible. At the same time, the government should establish step-by-step reductions, to be imposed by law, which would recognize the historical contributions to emission reductions already made, as well as the current environmental problems and needs. Once the reductions and their timing have been set forth, it should remain the choice of the Companies to then implement appropriate compliance measures.

Question: "Do mechanisms exist which enable governments to mandate further emission reductions in an enforceable manner?"

Answer: At present, such mechanisms do exist, but new laws should be considered, at both the federal and provincial levels, to provide a solid foundation for action. To date, the role of the Federal Government in the reduction of SO_2 has been limited to issues with international implications. The provincial role in this area of air pollution control has been preeminent, because historically air pollution was considered to be a local problem. However, the current situation

> involving Sudbury (and other sources in Ontario, other provinces and the United States) demonstrates that the problems due to air pollution are concurrently local, interprovincial, and international.
>
> In this situation, the role of the Federal Government has been to negotiate at the international level while each province considers abatement alternatives which address local, interprovincial, and international concerns. In the case of Ontario, legal mechanisms have been used to implement such abatement actions on an "ad hoc" basis. However, in the longer term, Ontario, other provinces and the Federal Government will have to consider cooperative mechanisms to address the interprovincial and international aspects of air pollution. Meanwhile, governments must review their present laws to develop mechanisms of air pollution control which recognize the non-local aspects of air pollution. We feel that such longer term reviews should take place but that such reviews need not impede undertaking preliminary measures to reduce air pollution in the Sudbury Basin.

We would be remiss if we failed to recognize the invaluable assistance and guidance of all our consultants and advisers.

While we gratefully acknowledge our reliance upon their expertise, we accept the sole responsibility for the contents of this report.

All of which is respectfully submitted,

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EXECUTIVE SUMMARY

Over one hundred companies have been involved in the mining and smelting of ore in the Sudbury Basin since the first smelter was constructed at Copper Cliff in 1888. However, after 1930, only Inco Limited and Falconbridge Limited continued operations in this area.

The municipal taxes and wages paid by these two large Companies have supported, to a great extent, the growth of the City of Sudbury and the economy of the surrounding region. Even though the revenue and employment generated by the production of nickel, copper and other metal products have proved a tremendous boon to the region in particular and to the country as a whole, the mining and smelting operations of these two Companies have also resulted in adverse environmental impacts.

The chief causal agents of this environmental damage have been sulphur compounds and metallic particulates. It is estimated that, during the past ninety years, more than one hundred million tonnes of sulphur dioxide have been released into the skies over Sudbury.

The barren aspect of much of the Sudbury environment was mute, but compelling, evidence of the serious threat that high levels of sulphur dioxide and metals posed to the local forests and agriculture. To reduce these damages, process changes were implemented by the Companies and abatement control programs were imposed by provincial agencies. As a result of these measures, approximately 70% of the sulphur in the ore is currently contained, but the remaining emissions are vented through stacks. This procedure brought about improvements in ambient air quality by dispersing much of the sulphur outside the immediate region.

By the 1970's, a new environmental hazard was receiving worldwide recognition. The long range transport of air-borne pollutants and their subsequent deposition far from their source of emission was being documented. Further, the problem of lake acidification was being linked, in part, to the emissions of sulphur dioxide from tall stacks hundreds of kilometers distant from the impacted area.

Previous efforts at controlling emissions were inadequate to deal effectively with this newly understood phenomenon. Some controls placed on the Sudbury smelters were shown to exacerbate the problem of long range transport; in addition, they allowed emissions that would still lead to the further acidification of the sensitive local environment. However, at that time, regulators did not possess the necessary scientific knowledge to specify the emission reductions needed to ensure either local or long range environmental protection.

In 1973, the Ontario Ministry of the Environment initiated the Sudbury Environmental Study to compile the scientific data necessary to determine the reductions in sulphur dioxide and particulate emissions which would ultimately achieve levels of deposition acceptable to the local environment. Eventually, other provincial and federal research efforts were developed to address the broader question of lake acidification and long range transport.

In May of 1980, recognizing that further reductions were required, the Ontario/Canada Task Force was established to investigate and evaluate air pollution abatement options for Inco Limited and Falconbridge Limited.

On the basis of completed environmental research, the Task Force has concluded that emission reductions in the Sudbury region have resulted in measurable improvements in the local aquatic environment. Since the local environment is also subject to acid deposition from outside sources, even the complete elimination of smelter emissions would be insufficient to protect all of the region's sensitive environment. These local emissions, however, still constitute the single largest contribution to local acidification. Further, they also contribute to total deposition in sensitive remote areas, from Muskoka - Haliburton in Ontario to the province of Nova Scotia. Therefore, any North American commitment to reducing "acid deposition" to acceptable levels must include effective abatement in Sudbury as an essential component.

To complete the technical analysis mandated by its terms of reference, the Task Force examined the past and present production processes used by Inco and Falconbridge and their concomitant pollutant emissions. Appropriate process changes and compatible abatement technologies that would reduce emissions were then documented for each Company. This analysis showed that sulphur dioxide control technologies also resulted in a reduction in particulate emissions.

The opportunity for abatement varied according to the scope and nature of the production facilities of each Company. Reductions in sulphur dioxide could be effected by:

- controlling the amount of sulphur entering the smelter in the ore concentrate;
- instituting process modifications to produce "strong" smelter off-gases which can be used to make sulphuric acid;
- cleaning the weak residual off-gases with traditional pollution abatement devices.

Since Inco has not changed its basic nickel smelting process significantly in the past fifty years, modernization of its operations with new smelter technology would offer the greatest opportunity for emission reduction. On the other hand, Falconbridge Limited has recently completed major smelter renovations. Therefore, further reductions in sulphur dioxide emissions for Falconbridge could be achieved by sulphur rejection from the concentrate and, to a lesser degree, by further process modifications. Both Companies could institute weak gas treatment but this process would not result in improvements in productivity and process efficiency. Of the major abatement programs investigated, capital costs range from $3.5 to $62 million for Falconbridge Limited and $75 to $524 million for Inco Limited in 1982 dollars. These costs relate to a range of emission levels of 267 to 36 tonnes per day for Falconbridge and 1,045 to 43 tonnes per day for Inco.

The ability of each Company to shoulder the burdens of an expensive abatement program rests primarily on its future revenues and its ability to raise funds. The Task Force has examined world nickel and other metal markets and developed demand, supply and price forecasts. Based upon these forecasts, the Task Force anticipates that the world nickel market, while recovering from its present low, will remain sluggish and that the entry of new producers into the present overcapacity situation will cause real prices to remain stable or even to decline over the forecast period.

As a result, the Companies will have to pay particular attention to their costs to remain competitive. Continued gains in productivity, fuel savings and efficiencies due to modernization will need to be aggressively pursued. Although the fundamental changes that have taken place in the nickel markets mean that Inco and Falconbridge are unlikely to continue to experience their past robust earnings, both Companies appear to have the capability to adapt to market changes and thereby, to remain viable corporate enterprises.

Aside from capital costs, the abatement programs studied may confer positive or negative influences on a company's operating costs. Process changes may allow savings in energy, increased revenues through by-product sales and improvements in productivity, while weak gas treatment equipment may incur additional costs. A number of methodologies were used to examine the costs to the Companies of the various abatement programs. An examination of the financial attractiveness of meeting successively lower levels of emissions was also undertaken. This analysis indicated that Inco smelter modernization by itself is economically viable but when coupled with other modifications to achieve further emission reductions, it is less attractive.

The Task Force estimated the socio-economic impacts of representative abatement programs on the Sudbury region. The large cost abatement options themselves will offer short-term employment opportunities. In the long run, due to losses of permanent jobs, they will produce small but negative changes in the community in terms of declines in population, income, retail sales and municipal revenues. These changes are not large relative to the more significant adverse effects which the community is experiencing as a result of current layoffs and shutdowns at the two smelters, but will nonetheless worsen the region's poor economic situation.

The Task Force assessed the effectiveness of present legislation to ensure compliance with any new emission target and examined the roles of the Federal Government and the Ontario Provincial Government in dealing with emission controls. It is suggested that the Federal Government's activity should be extended to include not only its present control over the long range transport of pollutants across international boundaries, but also the movement of these pollutants across provincial boundaries.

With respect to provincial legislation, it is felt that the Province of Ontario currently has effective standards for controlling local single point sources of emissions. However, because of the complexity, severity and scope of damage, additional bolder legislative controls are required to deal comprehensively with all emissions originating from the two Sudbury sources.

It is the view of the Task Force that further abatement action to control particulates and sulphur dioxide should occur in the Sudbury area. This action should be a phased program of emission reductions which incorporates process changes and the installation of abatement equipment. The legal mechanisms exist to begin action now. New federal and provincial legislation must be considered to address the problem of non-local air pollution damage over the longer term. However, the Task Force believes that the development of new control instruments need not impede undertaking preliminary measures to reduce air pollution in the Sudbury Basin.

1. INTRODUCTION

In early 1980, the Governments of Ontario and Canada agreed that the seriousness of the acid rain phenomenon warranted urgent action to reduce the emissions of acid-causing pollutants. It was also recognized that Governments must, for their part, inform themselves of the implications of various control options in the broader social, economic and environmental contexts. To that end, in May of 1980, the Ontario/Canada Task Force was established in order to investigate air pollution abatement options for Inco Limited and Falconbridge Limited in the Regional Municipality of Sudbury, Ontario.

The Task Force membership consisted of senior representatives from the Ontario Ministries of the Environment and Natural Resources and the Federal Departments of the Environment and Energy, Mines and Resources. In addition, each Government nominated one public representative to the Task Force.

The actual study objectives for the Task Force were the following:

- To identify and enumerate the environmental, economic and social consequences of alternative air pollution abatement options which will assist in making policy decisions relevant to the Inco and Falconbridge smelting facilities in the Sudbury area.
- To develop technical "abatement cost functions" for all air emission sources from the Companies' Sudbury area facilities at current installed capacity.
- To assess the economic impacts of abatement programs on the Companies.
- To evaluate the consequences of alternative government policies intended to induce abatement by the Companies.
- To relate abatement options and costs to available environmental effects data.

The Task Force was established for the purposes of generating the necessary data and information upon which policy alternatives for the reduction of emissions at these two Sudbury sources could be developed and evaluated. Consequently, the Task Force needed to undertake a number of complex studies requiring expert assistance. The Task Force's analysis of this investigative work is presented in this document.

The Task Force reviewed the emissions of SO_2 and particulates from more than 90 years of mining and smelting activities in the Sudbury area as well as their resultant environmental damages. Chapter 2 summarizes this historical review of emissions and the past efforts by both Inco Limited and Falconbridge Limited to reduce their emissions.

The Task Force believes that production cutbacks alone do not constitute an acceptable means of emission reduction, since other pollution control options are available.

Chapter 3 outlines the processes used by Inco to produce nickel from the Sudbury ores. Various stages of each process result in sulphur dioxide emissions. Both the quantities emitted and the concentrations at each stage are identified, since they affect the need and methods required for control of the emissions. The discussion then proceeds to the possibilities of reducing emissions by various technological means.

At the end of Chapter 3, the technologies selected for further examination are listed. In Chapter 4, these technologies are described in greater detail and then assessed with respect to their capability of reducing sulphur dioxide and particulate emissions, their costs, their production of by-products and/or wastes and a time scale for their installation.

A similar analysis was conducted for Falconbridge. Processes used by Falconbridge are described in Chapter 5, with the emphasis on the quantity and concentration of sulphur dioxide emissions at various stages. In Chapter 6, the technologies selected as feasible for implementation at Falconbridge are discussed in greater depth.

Nickel is a metal commodity and, as such, world supply and demand for nickel affects the operations of both Inco and Falconbridge. For this reason, in Chapter 7, the Task Force has considered the outlook for world nickel markets and developed demand, supply and price forecasts. The implications of the nickel market forecast for Inco and Falconbridge are also summarized.

In Chapter 8, the different abatement programs for Inco and Falconbridge are analysed with regard to the costs of control and actual emissions reduced. A number of methodologies were used to examine the costs to the Companies of the various abatement programs. Then, in order to determine if emission reductions would protect the Sudbury local environment, as well as address the long range transport aspects, the environmental situation is reviewed in Chapter 9. As a final assessment, the nature, timing and extent of the socio-economic effects of selected abatement programs for both Inco and Falconbridge on the Regional Municipality of Sudbury are identified in Chapter 10.

Chapter 11 presents some abatement mechanisms and policy considerations and discusses the Federal Government's role in controlling emissions, the role of the Province of Ontario in this same area and possible interim and long-term options for pollution abatement.

2. HISTORICAL REVIEW OF SULPHUR DIOXIDE EMISSIONS AND THEIR CONTROL AT INCO LIMITED AND FALCONBRIDGE LIMITED

Abstract

Prior to the introduction of modern smelting practices, the Sudbury ores were roasted in open heaps. This practice, which terminated in 1929, caused elevated ground level concentrations of sulphur dioxide in nearby populated areas. Complaints from the residents regarding damages and nuisance from sulphur fumes prompted the Provincial Government to intervene. Consequently, in 1915, an Order-in-Council was passed by which all patents, issued to settlers of land within a defined area, had a clause exempting the mining companies from liability due to smoke damages. In addition, efforts were made to relocate the roast yards further away from populated areas. Early government involvement also resulted in the introduction of legislation (The Damages By Sulphur Fumes Arbitration Act) to facilitate the settlement of claims resulting from injury to vegetation by sulphur fumes and in the formation of the Sulphur Dioxide Committee to determine if smelter gases were causing injury to forest growth.

Before the issuance of the first Control Order on Inco Limited in 1970 to control SO_2 emissions from its Sudbury operations, the Company had already implemented a number of programs which resulted in a gradual increase in the degree of sulphur containment. These programs, however, were largely oriented at increasing production capacity in a cost effective manner. They comprised pyrrhotite rejection, liquid SO_2 production and sulphuric acid manufacture. These sulphur containment practices resulted in an overall increase in SO_2 containment (sulphur contained/sulphur in ore) from about 20% in 1955 to about 30% in 1969. Further improvements by Inco Limited have resulted in increasing its overall sulphur dioxide containment to about 66% in the late 1970's. Increased containment, through additional pyrrhotite rejection, is expected in order for the Company to meet more stringent SO_2 emission limits in 1983. The basic Inco Limited smelting process, however, is substantially the same as it was 50 years ago. Inco Limited is currently testing, on a commercial scale, a new smelting process at its Thompson smelter in Manitoba for possible application in Sudbury. This process, if implemented, would effect significant reductions in SO_2 emissions to the atmosphere.

Prior to the issuance of the first Control Order on Falconbridge Limited in 1969 to reduce SO_2 emissions from its smelting operations at Falconbridge, the Company reduced its overall emissions largely through pyrrhotite separation and rejection. This sulphur containment practice effected reductions in SO_2 emissions to the atmosphere on a nickel production basis. The commissioning of a new smelting

process at Falconbridge (fluid bed roaster/electric furnace smelting, sulphuric acid production) in 1978 has resulted in an improvement in overall sulphur dioxide containment (sulphur contained/sulphur in ore) from about 17% in 1953 to about 84% in 1980. These figures include 5% of the sulphur in the ore that remains in the matte which is shipped to Norway.

This new smelting process enabled the Company to meet overall SO_2 emission requirements imposed by the Provincial Government. However, the Company will not be able to comply with the last item in its current control program which requires meeting the provincial half-hour SO_2 standard at point of impingement. The Company has undertaken a research and development program aimed at effecting further reductions in smelter SO_2 emissions at Falconbridge.

2.1 The Environmental Problem

The primary historical problem has been due to SO_2 and its associated compounds. Over the years, elevated concentrations and deposition rates of these pollutants have seriously affected the Sudbury area biosphere. This adverse impact on the environment began with the commencement of smelting operations in 1888 and has continued to this day, albeit at significantly reduced levels from the 1950's and 1960's. In addition, the transport of these pollutants over long distances, with the consequent impact on areas removed from Sudbury, has been recognized. Thus, the environmental problem is characterized by local and long distance components. Over the intervening years, various process changes by the Companies and abatement control programs imposed by provincial agencies have resulted in significant reductions in the emissions of SO_2 and other contaminants.

Additional concerns have also been identified in relation to the workroom environment and occupational exposure with respect to the smelting operations in the Sudbury area.

2.2 History of Smelter Technology in the Sudbury Area

It was not until 1888 that the first smelter was constructed at Copper Cliff.

During the years 1888 to 1929, ore was roasted in open heaps of various sizes. In the construction of these heaps, green ore was piled on a thick layer of wood which was then set alight. The fire was sufficiently hot to ignite the sulphur in the ore and the reaction became self-sustaining. Burning or roasting took from one to seven months to complete, depending upon the size of the heap. The roasted ore was then taken to the smelters for further processing. Approximately 28 million tons (25 million tonnes) of ore were smelted between 1890 and 1930 and it is estimated that approximately 11.2 million tons (10.2 million tonnes) of sulphur dioxide were emitted over this period. The practice of open roasting, which was largely responsible for damage to property and nuisance to residents, ceased in 1929 with the closure of the O'Donnell roast yard.

Throughout the mining history of Sudbury, over 100 companies initiated operations but most either failed or amalgamated to form larger companies. By 1930, all smelter operations had ceased to exist except for those of the International Nickel Company of Canada (now Inco Limited) located at Copper Cliff and at Coniston (Coniston smelter built in 1913). Only one company has successfully started up and grown since then, that company being Falconbridge Limited which was established at Falconbridge in 1930.

2.2.1 Inco Limited: Smelter Development

Until 1930, the treatment of the Sudbury nickel ores involved hand sorting to eliminate some of the barren rock, followed by open heap roasting and blast furnace smelting. The first attempts at effecting some management of SO_2 emissions comprised the relocation of roast yards further away from populated areas. Concurrently, smelters were built with progressively taller stacks.

The 50 year period following 1930 has seen prolific process innovations and witnessed phenomenal expansion in production capacity. Several of these technical changes have resulted in SO_2 emission reductions or management. The installation of multi-hearth roasters allowed the cessation of open heap roasting. Tall stacks and subsequent process operations aided in reducing the severity and frequency of ground level SO_2 fumigations, while dispersing smelter gases from the immediate industrial area.

In the 1930's, off-gases from copper converters were treated in a sulphuric acid plant to produce sulphuric acid. Later, excess off-gas from the copper flash furnace was also treated in this plant.

Pyrrhotite separation technology, developed in the 1940's, improved smelter efficiency while removing some of the sulphur from the concentrate feed. However, the subsequent roasting of pyrrhotite resulted in elevated SO_2 emissions. By 1958, Inco Limited was beginning to divert some of these SO_2 emissions to acid plants, producing sulphuric acid.

The early 1950's also saw the installation of a commercial scale SO_2 liquefaction plant to treat some of the emissions from the copper flash furnace at the Copper Cliff smelter.

These sulphur containment practices resulted in an overall increase in SO_2 containment from about 20% (sulphur contained/sulphur in the ore) in 1955 to about 30% in 1969.[1] A full chronology of these technical innovations is given in Appendix 2.1.

On the basis of the emissions data up to 1980, daily SO_2 emission rates (five-year means) from Inco Limited at its Sudbury operations ranged from about 2,300 tonnes to about 5,400 tonnes (see Figure 2.1). This wide range is believed to reflect variations in production rates and the implementation of the programs listed above including the commissioning of the Iron Ore Recovery Plant (IORP) in 1956. Annual SO_2 emissions from Inco Limited dating back to the 1940's and 1950's are also presented in Table 2.1. In addition, the percentage contributions from Inco Limited sources to the total emissions of major pollutants in the Sudbury Basin over the period 1973 to 1981 are presented in Table 2.2.

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[1] CURLOOK, W. June 4, 1980.
Remarks at the Ontario Ministry of the Environment Public Meeting to Discuss Proposed Control Order. Presented by Walter Curlook, President, Inco Metals (1980).

Over the last twenty-five years, Inco Limited has investigated and, in some cases, implemented new technologies which have eventually proven to be technically or economically unfeasible. While requiring years of research and tens of millions of dollars in capital expenditures, these investments have made minimal impact on SO_2 emissions. The major areas of research included:

1957-58	production of elemental sulphur from IORP SO_2 emissions;
1967	construction of a fluid bed roaster at the Copper Cliff smelter to modernize the plant and produce strong off-gas to make acid;
1968-78	$14 million spent for research on hydrometallurgical treatment of nickel concentrates;
1977	nickel flash furnace and acid plant.

Notwithstanding the above complications, substantial progress, which will be described in subsequent sections, has been made since 1970 in the containment of sulphur.

2.2.2 Falconbridge Limited: Smelter Development

Prior to the issuance of the first Control Order on Falconbridge Limited in 1969, the Company reduced its SO_2 emissions largely through pyrrhotite separation and rejection. This sulphur containment practice effected reductions in SO_2 emissions to the atmosphere on a nickel production basis. For example, in 1940, the ratio of tonnes of sulphur emitted per tonne of nickel produced was about 7.8, whereas, in 1970, the ratio had decreased to about 5.2, resulting in a 33% improvement in sulphur containment expressed on the basis of nickel production. However, the overall SO_2 emissions to the atmosphere were higher in the 1950's, 1960's, and early 1970's compared to those in the 1940's (see Figure 2.1 and Table 2.1) due to higher production levels and the commissioning of the pyrrhotite treatment plant in 1953. The percentage contributions from Falconbridge Limited to the total emissions of major pollutants in the Sudbury Basin over the period 1973 to 1981 are presented in Table 2.2.

Falconbridge also devoted research time and capital resources in an attempt to develop smelter improvements which, unfortunately, proved to be unsuccessful. These included: a nickel/iron refinery with elemental sulphur recovery; a roasting/briquetting process that would produce strong off-gas suitable for acid production; and hydrometallurgical research. In the mid-1960's, the Company undertook the pilot plant development and economic evaluation of a process to convert SO_2 roaster off-gas to elemental sulphur. At that time, there were expectations that about 90% of the sulphur present in fluid bed roaster off-gases would be recovered, thereby effecting significant reductions in overall SO_2 emissions to the atmosphere.

2.3 Regulating Emissions

2.3.1 Early Government Involvement

With the development of the mining industry around Sudbury came the growth of the city itself, the need for a service sector and a source of agricultural commodities. Consequently, the number of complaints from residents regarding damages and nuisance from sulphur fumes also grew. To relieve the pressure from these complaints, the Canadian Copper Company and the Mond Nickel Company petitioned the Minister of Mines to have certain lands withdrawn from further agricultural settlement. In 1915, an Order-in-Council was passed by which all patents, issued to settlers of land within the withdrawn area, consisting of approximately twelve townships, had a clause exempting the mining companies from liability due to smoke damages.

As early as 1921, the Provincial Government introduced legislation (The Damages By Sulphur Fumes Arbitration Act, 1921) to facilitate the settlement of claims resulting from injury to vegetation by smelter fumes. This Act was repealed and replaced by The Damages By Sulphur Fumes Arbitration Act, 1924. The first Sulphur Fumes Arbitrator took office in 1925.

In 1944, the Sulphur Dioxide Committee, initially known as the Committee on the Investigation of Sulphur Smoke Conditions and Alleged Forest Damage in the Sudbury Region, was formed at the request of the Department of Lands and Forests with representatives from the Department of Lands and Forests, Department of Mines, Inco Limited, Falconbridge Limited and other agencies acting in advisory capacities. The primary objectives of the Committee were to determine if sulphur dioxide and other smelter gases were causing injury to forest growth, and if so, the area over which this condition extended and the remedies that could be applied. The first SO_2 ambient concentration monitoring network was established in the Sudbury area in the mid-1940's. This network permitted investigators to relate visible vegetation (forest) injury to measured ambient SO_2 levels and to determine the aerial extent of this impact. The objectives of this Committee were only partly realized since its work was terminated in 1972 at which time the bulk of its activities was taken over by the Ministry of the Environment.

2.3.2 Inco Limited

In July of 1970, the first Control Order to limit SO_2 emissions from its Sudbury operations was issued to Inco Limited. The control program required the construction of a 381 m stack and a stepwise reduction in SO_2 emissions from 5,200 tons (4,716 tonnes) per day to 750 tons (680 tonnes) per day by December 31, 1978 from the Copper Cliff smelter. Negotiations between the Company and the Ontario Ministry of the Environment resulted in a rescheduling of the emission targets as witnessed in the Amending Control Orders issued in 1972 and 1973. When it became apparent that the 750 tons (680 tonnes) per day limit for the smelter would not be met, the existing Order was revoked in the fall of 1977 and in July 1978 a new Control Order was issued.

The new Control Order required that sulphur dioxide emissions from the Copper Cliff smelter be limited to 3,600 tons (3,265 tonnes) per day and required control of operations (at both the Iron Ore Recovery Plant and the Copper Cliff smelter) to ensure compliance with specified ground level SO_2 concentrations (0.25 ppm hourly average for emissions from the Iron Ore Recovery Plant complex alone; 0.50 ppm hourly average for emissions from the Copper Cliff smelter complex either alone or in combination with emissions from the Iron Ore Recovery Plant complex and fugitive smelter emissions). This Order was dated to expire on June 30, 1982. The rationale for the extension in time of the emission limit of 3,600 tons (3,265 tonnes) per day from the smelter was largely based on several factors. By the end of 1977, the extent and severity of the acid rain problem was becoming more apparent and information on the metal content of rainfall was becoming available, highlighting a further potential problem. Therefore, from an environmental point of view, any control program developed for the smelter had to be evaluated in light of a number of potential environmental implications. This situation was further complicated by a lack of hard scientific data to clearly define the extent and nature of these environmental problems, thereby not allowing for corrective measures to be defined. Consequently, it was judged best to await the results of the Sudbury Environmental Study, established by the Ministry in 1973 to provide the scientific data necessary to determine the reductions in SO_2 emissions required to achieve environmentally acceptable levels for the local environment, before mandating further emission reductions.

In September of 1980, an Amendment to the July 1978 Control Order was issued. At the same time, Regulation 712/80, which required the Company to limit sulphur dioxide emissions from the Copper Cliff smelter to less than 2,500 tons (2,268 tonnes) per working day immediately, with a reduction to 1,950 tons (1,769 tonnes) per working day by 1983, was passed.

The basis for these new requirements developed after 1978 as a result of a preliminary assessment of the potential environmental implications associated with the operation of the Copper Cliff smelter. It was believed that action was required to reduce emissions of sulphur dioxide from the smelter and to minimize environmental problems associated with possible production increases. It was recognized by the Ministry that the steps in this proposed program would not totally solve local or continental environmental problems but that they would form a basis for further control requirements as additional data became available.

In summary, the Company was able to meet all the control requirements as specified by the Ministry except for the last step (reduction of sulphur dioxide emissions from the Copper Cliff smelter from 3,600 tons (3,265 tonnes) per day to 750 tons (680 tonnes) per day) by closing the Coniston smelter; building additional acid plant capacity at the Iron Ore Recovery Plant; building the Clarabelle concentrator; and modifying the old Copper Cliff concentrator for more efficient pyrrhotite removal. In so doing, the Company improved its overall sulphur dioxide containment (expressed as sulphur contained/sulphur in ore) from about 30% in the late 1960's to about 70% in the late 1970's.[2] Inco's ongoing smelter improvements and actions taken in response to Regulation 712/80 are discussed in Section 2.4.1.

2.3.3. Falconbridge Limited

The first Control Order to limit sulphur dioxide emissions from the Falconbridge smelter operations was issued to Falconbridge Limited in November, 1969. This control program required a 55% reduction in SO_2 emissions by December 31, 1975 from 1,028 tons (932 tonnes) per calendar day in 1969 to 465 tons (422 tonnes) per calendar day in 1975 on an annualized average basis.

[2] Ibid.

The technology Falconbridge had planned to use to meet the control terms proved to be unsatisfactory and, in 1973, a new Control Order was issued. This Order entailed a scheduled stepwise reduction in SO_2 emissions to 465 tons (422 tonnes) per day by May 31, 1979 and further required the Company to meet ambient SO_2 concentrations of 0.3 ppm (830 ug m^{-3}) averaged over 30 minutes by December 31, 1983.

Falconbridge proposed to meet these requirements through the installation of a two-line fluid bed roasting/electric furnace smelting system with a single sulphuric acid plant to treat roaster off-gases from both lines.

A lengthy strike and adverse economic conditions forced the Company to ask for an extension of the schedule. This was duly granted and embodied in an Amending Control Order in 1977. In essence, under the revised program, Falconbridge Limited constructed both smelting lines at the same time instead of sequentially as originally proposed.

The first line electric furnace smelting process (with acid plant) was started up in May 1978 and was operated along with the blast furnace until July of 1978, at which time the smelter was shut down for summer vacation. Following summer vacation, the one-line smelter operated alone, i.e the old smelter operation was discontinued almost one year ahead of Order requirements. Pyrrhotite roasting on the second line to produce market sulphuric acid commenced in September of 1978 and continued until November of 1979.

The second line of the smelter was prepared for the treatment of concentrate for early 1980 and both lines are currently operating on a copper/nickel concentrate producing matte and sulphuric acid. Emission levels below 465 tons (422 tonnes) per day are being maintained.

In summary, the Company was unable to meet the schedule of the initial control program laid out in 1969 due to the failure of the new process technology that would have ensured compliance. However, it was able to meet the overall SO_2 emission requirements of the control program (emission target of 465 tons (422 tonnes) per day) largely through the installation of a new smelting process with sulphur fixation as sulphuric acid and, to a lesser degree, through more efficient separation and rejection of pyrrhotite. In so doing, the Company improved its overall sulphur dioxide containment (expressed as sulphur contained/sulphur in ore) from about 17% in 1953 to about 84% in 1980. About 5% of the sulphur in the ore remains in the matte which is shipped to a refinery in Norway. This 5% is included in the overall SO_2 containment figure given above.

2.4 Current Status

2.4.1 Inco Limited

The control program presently in effect for Inco Limited (1980 Control Order and Regulation 301 (R.R.O. 1980)) requires the Company to emit no more than 2,500 tons (2,268 tonnes) per working day from the Copper Cliff smelter complex (under Regulation 301 (R.R.O. 1980)) averaged over twelve month periods ending at each calendar quarter. This emission level is to be met, over a twelve month period, up to the period ending at the end of the third quarter of 1983, that is up to and including the period from October 1, 1982 to September 30, 1983. Thereafter, emissions during each twelve month period, ending at the end of the fourth calendar quarter of 1983 (i.e. January 1, 1983 to December 31, 1983) and ending at each calendar quarter thereafter, shall not exceed, on the average, 1,950 tons (1,769 tonnes) per working day.

SO_2 emissions from the Iron Ore Recovery Plant, as required by the 1980 Control Order, cannot exceed 250 tons (227 tonnes) per working day. In addition to these restrictions on total SO_2 emissions, the Copper Cliff smelter complex and the Iron Ore Recovery Plant require control of their operations to ensure compliance with specified SO_2 ground level concentrations. To date, the Company has been able to comply with these total SO_2 emission limits largely as a result of reduced production levels in light of poor metal market conditions. The 1,950 tons (1,769 tonnes) per working day emission level for the Copper Cliff smelter complex will be met with additional pyrrhotite rejection at the Copper Cliff mill.

The Company is currently testing a commercial scale roast/reduction smelting process at Thompson, Manitoba, for possible application at Copper Cliff. The process would produce a high strength SO_2 off-gas suitable for the manufacture of sulphuric acid. This technology has the potential for increasing metal recoveries, improving workplace conditions, increasing productivity and reducing emissions. The Thompson tests have cost approximately $26 million to date and should be completed in 1982.

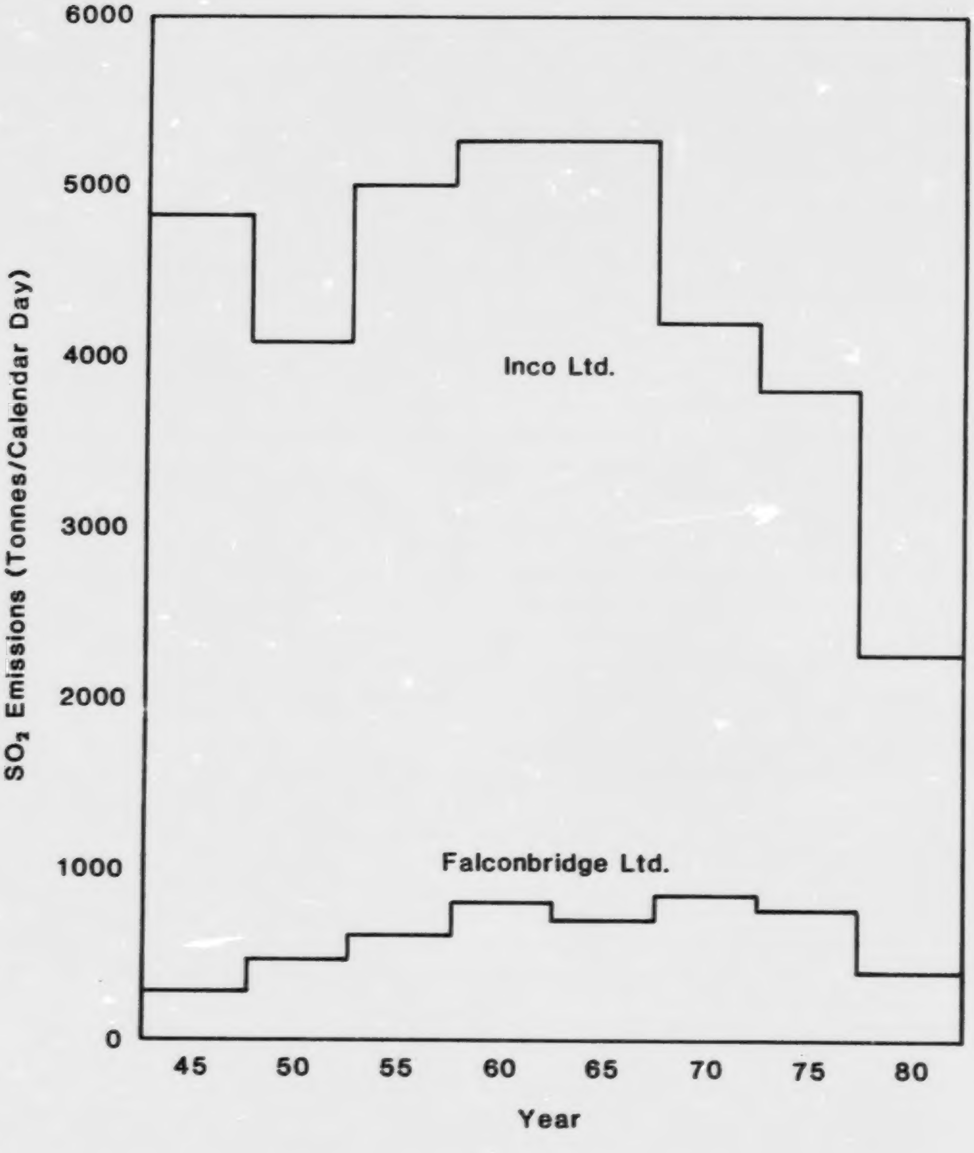
2.4.2 Falconbridge Limited

To date, the control program presently in effect for Falconbridge Limited (1977 Amending Control Order) has been met. The final requirement of this Order is for the Company to reduce emissions of SO_2 from the Falconbridge smelter complex by December 31, 1983, so that, in the aggregate, they comply with the standards prescribed in Schedule 1 of Regulation 15 under The Environmental Protection Act, 1971. This standard for SO_2 is a ground level concentration of 0.3 ppm (830 ug m^{-3}) at point of impingement for a half hour average.

As required by this Amending Control Order, the Company submitted a report in December 1980 addressing how it was intending to reduce emissions to comply with this SO_2 standard. In the spring of 1981, Company representatives advised that a reduction in total SO_2 emissions could not be effected by December 31, 1983 to comply with the final requirement of the 1977 Amending Control Order. The Ministry was further advised that the Company had undertaken a metallurgical research and development program with the aim of further reducing SO_2 emissions from the Falconbridge smelter complex. This research program involves higher degrees of roasting in the fluid bed roasters, slag cleaning, SO_2 absorption from dilute gas streams, a converter gas study and an acid plant capacity study. In addition, the feasibility of adopting an intermittent emissions reduction program analogous to the one used by Inco Limited will be investigated. The Company estimates that this research program will cost over $5 million and may be completed by the end of 1984.

FIGURE 2.1

POSTWAR SO_2 EMISSIONS FROM SUDBURY AREA SMELTERS



*SO_2 Emissions (Tonnes/Calendar Day) Averaged Over 5 Year Intervals

TABLE 2.1

SULPHUR DIOXIDE EMISSIONS FROM THE INCO LIMITED AND FALCONBRIDGE LIMITED OPERATIONS IN THE SUDBURY BASIN

	SULPHUR DIOXIDE EMISSIONS (Tonnes Per Calendar Day)*	
YEAR	INCO	FALCONBRIDGE
1940	4647	278
1950	4766	462
1955	5024	
1956	5614	800
1957	5837	
1958	3508 (4707)	780
1959	5673	
1960	6218	816
1961	6086	
1962	4893	756
1963	4582	
1964	5129	646
1965	6166	
1966 (strike year - Inco)	5104 (5447)	790
1967	5711	813
1968	5755	935
1969 (strike year - Inco and Falconbridge)	3589 (5552)	651 (880)
1970	5454	929
1971	5118	992
1972 **	4162 (4416)	885 (915)
1973 ***	3249 (3448)	751
1974	3331	707
1975 (strike year - Inco and Falconbridge)	3282 (3385)	534 (668)
1976 +	3340	523 (560)
1977 +	3115	548 (619)
1978 +(strike year - Inco)	1553 (2613)	321 (374)++
1979 +(strike year - Inco)	1118 (1933)	241 (251)
1980 +	2225	337 (351)
1981 **	1981 (2146)	312 (334)

* Tonnes per operating day within parentheses. For the other years, the smelters were operating every day of the year.

** Summer vacation shutdown (Inco and Falconbridge).

*** Summer vacation shutdown (Inco).

+ Production shutdown (Falconbridge).

++ New smelting process implemented that year.

TABLE 2.2

% SOURCE CONTRIBUTIONS OF MAJOR POLLUTANTS EMITTED IN THE SUDBURY BASIN (1973-1981)

SOURCE	POLLUTANT SO_2	SO_4	METALS	TOTAL PARTICULATE
Inco 381 m Stack	78	77	55	75
Inco IORP 191 m stack	5	18	32	16
Fugitive Emissions (Copper Cliff smelter)	1-2	1	9	3-4
Falconbridge smelter 93 m stack	16	5	4	6

APPENDIX 2.1

INCO SMELTING HISTORY

1883	Sudbury ore body discovered during the construction of the CPR railway.
1888	First smelting operations begun at Copper Cliff.
1903	Canadian Copper Company and Orford Copper Company united to form the International Nickel Company.
1913	International Nickel Company's Coniston smelter built with a 121 meter smoke stack.
1929	The closing of the last open heap roasting operations. International Nickel Company integrated with the Mond Nickel Company to form the International Nickel Company of Canada (later changed to INCO Limited).
1930	The opening of the International Nickel Company Copper Cliff smelter with stacks (by the mid 1930's) reaching 106 and 152 meters.
mid 1930's	Acid plant constructed at the Copper Cliff smelter, initially for the treatment of off-gases from the copper converters and later, for treatment of excess off-gas from the flash furnaces together with converter off-gas.
1946	First successful tests of separation of pyrrhotite by magnetic means.
1947	Laboratory tests on ammonia leaching of pyrrhotite showed promising results. Pilot plant tests undertaken on flash smelting of copper concentrates, 20 tons (18.1 tonnes) per day (tpd).
1949	Started pilot plant at Coniston for the roasting and ammonia leaching of pyrrhotite.
1952	New 500 tons (454 tonnes) per day oxygen flash furnace and 375 tons (340 tonnes) per day oxygen plant commissioned at Copper Cliff. Commercial scale production of liquefied sulphur dioxide started by CIL at Copper Cliff.

APPENDIX 2.1 (continued)

early 1950's	Coniston sinter plant commissioned with a 114 meter stack.
1953	1,000 tons (907 tonnes) per day copper flash furnace installed, replacing 500 tons (454 tonnes) per day unit. Commenced construction of first unit of Iron Ore Recovery Plant (IORP).
1955-56	Started operation of first two units of IORP, capacity 1,000 tons (907 tonnes) per day of pyrrhotite, producing 260,000 tons (235,820 tonnes) per year of iron ore pellets. Emissions dispersed by a 194 meter stack.
1958	First acid plant commissioned at the IORP, with a capacity of 400 tons (363 tonnes) per day.
1963	Completed first major expansion of IORP, capacity increased to 3,000 tons (2,721 tonnes) per day pyrrhotite, producing 800,000 tons (725,600 tonnes) per year of iron ore pellets. Second acid plant commissioned at IORP; capacity increased to 1,000 tons (907 tonnes) per day.
1967	Started construction of No. 1 fluid bed roaster on No. 1 reverberatory furnace to begin modernization of the Copper Cliff smelter and to produce a strong SO_2 gas for eventual recovery as sulphuric acid.
1967	Third acid plant commissioned at IORP raising acid capacity to 2,500 tons (2,268 tonnes) per day. Old acid plant at smelter shut down; capacity replaced by IORP capacity. Started major expansion of IORP, intended to raise pyrrhotite treatment to 4,500 tons (4,082 tonnes) per day to produce 1,150,000 tons (1,043,050 tonnes) per year of iron ore pellets. Completion of construction of new Frood-Stobie concentrator.
1968	Expanded copper flash furnace to 1,500 tons (1,361 tonnes) per day.
1969-71	Built Clarabelle concentrator and modified the old Copper Cliff concentrator for more efficient pyrrhotite separation.

APPENDIX 2.1 (continued)

1972	The new 381 meter "super stack" was commissioned at the Copper Cliff smelter. A mineral dressing test centre, primarily for studies on pyrrhotite separation and rejection, was built. The Coniston smelter was permanently shut down.
1973	Adoption (voluntary) of an itermittent SO_2 emission reduction program to improve Sudbury area ambient air quality by meteorological forecasting and reducing smelter operations during periods unfavourable for atmospheric dispersion.
1974	IORP acid plant capacity increased to about 3,000 tons (2,721 tonnes) per day.

APPENDIX 2.2

FALCONBRIDGE SMELTING HISTORY

1930	The establishment of the new Falconbridge Nickel Mines smelter with emissions dispersed through a 94 m stack.
1953	Commissioning of the pyrrhotite treatment plant with emissions vented through a 137 meter stack.
1972	Nickel/iron refinery permanently shut down.
1978	First line of new fluid bed roaster/electric furnace smelter with acid plant is started up.
1980	Second line of fluid bed roaster/electric furnace smelter commissioned.

3. THE PRODUCTION PROCESS AT INCO LIMITED: SOURCES OF EMISSIONS, PROCESS CHANGES AND ABATEMENT TECHNOLOGIES

Abstract

The processes used by Inco to produce nickel from the Sudbury ores are outlined, with a brief description of the milling process by which concentrates (copper and copper/nickel) are separated from the worthless minerals (gangue) and from an iron sulphide pyrrhotite fraction.

The present pyrometallurgical process used at Copper Cliff and the sulphur balance for this process are outlined in diagram form (see Figures 3.1 and 3.2). The smelter operations are described in detail in the text.

The emphasis of the description is on the sulphur dioxide emissions. Both the quantities emitted and the concentrations are dealt with since they affect the need and the methods required for control of the emissions.

Particulate metal emissions are also of concern from the environmental as well as workplace environment perspectives. Hence, a brief description of existing processes with respect to particulate emissions from the 381 m and 194 m stacks and from fugitive low level sources at the smelter is presented. Also discussed are the inherent large uncertainties associated with the determination of particulate emissions.

The copper circuit, with its flash furnace for smelting the copper concentrate and its associated liquid SO_2 plant, is described, followed by a description of matte treatment in the copper converters to remove any remaining sulphur and iron, leaving an almost pure metallic copper. The nickel circuit operation, with its multi-hearth roasters, reverberatory furnaces and nickel converters, is shown to give rise to weak gas streams while producing a metallic sulphide matte, which, by treatment in the matte processing plant, is separated into copper and nickel sulphides and a copper/nickel alloy. The latter is transferred to the refinery process; the copper sulphide goes to the copper converters while the nickel sulphide is roasted in fluid bed roasters to produce nickel oxide for refining. The roaster off-gas, though suitable for sulphuric acid manufacture, is emitted directly to the atmosphere.

The Iron Ore Recovery Plant (IORP) process operation is also described. The gases from this plant, which comprise about 23% of the total sulphur in the ore, are controlled by an acid plant, although some gas is by-passed and about 12% of the total gases generated escape to the atmosphere.

A detailed discussion of the sulphur emissions and other important aspects then follows. The impact of pyrrhotite rejection, the importance of the smelter copper and nickel circuit emissions, the converters, roasters and reverberatory furnaces, and the effects on the workplace of fugitive emissions are all addressed. The discussion then proceeds to the possibilities of reducing emissions by various means. The use of flash furnaces and changes to both the copper and nickel circuits are examined, including the possibility of using a continuous process. Major process changes to the copper smelting circuit are not thought to be desirable, but the use of fluid bed roasters and electric furnaces on the nickel circuit is suggested as well as extensions to the process of recovering SO_2 from both strong and weak gas streams.

In principle, methods of producing strong SO_2 concentration streams, to replace several of the existing weak streams, form the major thrust of the processes identified. Finally, a proposal by Inco to use the IORP fluid bed roasters and acid plants rather than to install new equipment throughout the Copper Cliff nickel smelter is described. This process would eliminate the use of the IORP for recovery of iron ore pellets and nickel oxide from the pyrrhotite, which would be discarded.

3.1 The Present Pyrometallurgical Process

3.1.1 Introduction

The nickel and copper in the ores of the Sudbury area occur in association with sulphur. Principal economic minerals are pentlandite, a nickel/iron sulphide, and chalcopyrite, a copper/iron sulphide. In addition to their valuable nickel and copper content, these minerals also contain 15 other metals including cobalt, gold, silver and the six platinum group metals in varying quantities. A third mineral, which is abundant in the Sudbury ores, is an iron sulphide, called pyrrhotite. Small amounts of nickel occur in solid solution in the pyrrhotite, which means that this nickel cannot be separated from the pyrrhotite by physical processing of the ores.

In addition to the sulphide minerals, the ore contains large quantities of worthless rock-forming minerals, referred to as gangue.

To produce pure metals from the ores, the gangue must be removed and the metals separated from each other. This is achieved by:

- processing the ores in mills (concentrators) to separate the sulphide minerals from one another and from the gangue, which is sent to waste disposal areas as tailings;
- smelting the mineral concentrates to produce fairly pure metallic nickel, copper, cobalt, and precious metals;
- refining the metal products from smelting to produce relatively pure metals.

In addition, some of the iron sulphide mineral (pyrrhotite) is treated to produce nickel oxide, iron ore pellets and sulphuric acid.

3.1.2 Sulphur Balance in the Present Pyrometallurgical Process

A diagram of the metals production processes at Inco appears in Figure 3.1. The process plants at Sudbury, where sulphur is removed in one form or another, are:

- the mills;
- the Copper Cliff Smelter
  - copper circuit
  - nickel circuit;

- matte processing;
- the Copper Cliff Nickel Refinery (CCNR);
- the Iron Ore Recovery Plant (IORP).

Figure 3.2 is a simplified sulphur balance diagram which shows the proportion of the total amount of sulphur in the mined ore that leaves the process at various points. The form in which the sulphur is eliminated (solid, liquid, or gas) and its ultimate disposition (sold to customers, sent to tailings areas or emitted to the atmosphere) are noted on the diagram.

The principal points to note from the diagram are:

- about one-third (33.8%) of the sulphur contained in the mined ore is emitted to the atmosphere in the form of gaseous sulphur dioxide (SO_2);
- solid waste, in the form of tailings from the mills and slag from the Copper Cliff Smelter, accounts for 41.4% of the total sulphur in the ore;
- two marketable by-products, sulphuric acid and liquid sulphur dioxide, contain 24.0% of the total sulphur.

The quantity of sulphur rejected in these various forms depends on the amount of ore processed. Based on actual 1980 operating statistics for Inco, the processing of approximately 10 million tonnes of ore resulted in total emissions to the atmosphere of about 812,000 tonnes of gaseous SO_2 or 2,225 tonnes per day. Nickel output at this level of production is of the order of 120,500 tonnes (265 million lb) per year.

3.2 Description of Present Process Operations and the Control of Sulphur Dioxide Emissions

In this section, each of the process operations which has a role in the elimination of sulphur contained in the ores is described, with emphasis on the aspects of the operations which contribute to SO_2 emissions and their control.

3.2.1 The Mills

Four mills (also called concentrators) serve Inco's Sudbury operations. They receive crushed ore from various mines in the area and, through further processing (ore concentration), reject unwanted materials and separate the sulphide minerals from one another. The ore concentration process can be viewed as having two stages:

- separation of the metallic sulphide minerals from the gangue (waste rock);
- separation of the nickel sulphides, copper sulphides and pyrrhotite (iron sulphide) from each other.

An important objective of ore concentration is the removal of iron and sulphur from the ore concentrate which will be processed in the smelter. Iron which enters the smelter must be combined with silica and removed as a slag and sulphur must be oxidized (i.e. combined with oxygen) to form gaseous SO_2. Consequently, there are economic and environmental advantages to rejecting iron and sulphur in the mills. The present ore concentration process at Inco works toward this objective by rejecting both iron and sulphur in the form of low nickel-content pyrrhotite which is sent to tailings disposal areas along with the gangue.

The mills produce three concentrates which are processed further in subsequent operations:

- a copper concentrate which goes to the copper circuit of the smelter;
- a nickel/copper concentrate which goes to the nickel circuit of the smelter;
- a concentrate of higher nickel-content pyrrhotite which is processed in the Iron Ore Recovery Plant (IORP).

Figure 3.3 shows the composition of the concentrates.

3.2.2 Copper Cliff Smelter

Inco's Copper Cliff smelter, which first went into operation in 1930, is a large complex covering some 350 acres of land. There are two basic streams of operation in the smelter:

- the copper circuit, which processes the copper concentrate from the mills;

- the nickel circuit, which processes the nickel/copper concentrate from the mills.

The function of both circuits is to remove iron and sulphur from the concentrates. An essential part of the smelting process is the formation of mattes. A matte is a mixture of sulphides, copper, nickel and iron, which results from fusion and partial oxidation of the concentrate. It is desirable that the matte, either copper matte or nickel matte, should have a high content of the valuable metal and low iron and sulphur contents.

3.2.2.1 Copper Circuit

The copper circuit at Inco produces copper matte by smelting the ore concentrate in an oxygen flash furnace, which is a relatively modern type of furnace. The concentrate is injected into the furnace in a stream of almost pure oxygen. Roasting and melting of the concentrate occur almost instantaneously, resulting in the formation of copper matte, slag and a low volume gas stream consisting of 70% to 80% SO_2.

The SO_2 gas is withdrawn from the furnace, then cleaned of most of the particulate matter and directed to the liquid sulphur dioxide plant, where it is further cleaned to remove particulate and water. The gas is liquefied by compression and cooling and is sent to storage tanks to await shipment to customers. Flash furnace off-gas in excess of that which can be processed in the liquefaction plant, which has a capacity of about 82,000 tonnes per year for liquid SO_2 production, by-passes the plant and is emitted to the atmosphere via the 381 m stack. As shown in Figure 3.4, approximately 3.5% of the sulphur in the mined ore is eliminated from the process in the form of liquid SO_2. The SO_2 which by-passes the plant plus the SO_2 contained in the plant's "tail gas" (i.e. the SO_2 which is not captured by the liquefaction process) account for 0.8% of the sulphur in the ore.

The copper matte produced in the flash furnace must be treated further, by a process called converting, to remove the remaining iron and sulphur. In converting, air or oxygen-enriched air is blown through the liquid matte to transform the sulphur into sulphur dioxide gas and the iron into an iron oxide which forms slag.

Blister copper, an almost pure (98% to 99%) metal, is produced in the converter and is transferred to the Copper Refinery for further treatment.

The copper converters produce about 90% of the copper circuit's atmospheric SO_2 emissions in an intermittent gas stream which has a variable concentration of SO_2, averaging about 4% by volume. The off-gas is directed to electrostatic precipitators for dust removal and from there to the 381 m stack.

The copper circuit contributes the largest fraction to the total fugitive smelter emissions of SO_2 and particulates, mainly as converter emissions (Table 3.1).

3.2.2.2 Nickel Circuit

The first step in the nickel circuit is the roasting of the nickel/copper concentrate in multi-hearth roasters. The roasting drives off slightly more than 20% of the sulphur, which enters the nickel circuit (equal to 5.7% of the sulphur in the mined ore) as SO_2, leaving a calcine. The SO_2 mixes with large volumes of air such that it amounts to less than 2% by volume of the total gas stream. The gas passes from the roasters to electrostatic precipitators and from there to the 381 m stack.

The calcine is transferred from the roasters to reverberatory furnaces which melt the calcine, remove more iron, burn more sulphur and produce another off-gas which is weak in SO_2 (2% by volume). The furnaces drive off 3.9% of the sulphur in the ore as SO_2, or about two-thirds as much as the roasters. Slag from the furnaces contains an additional 1.3% of the sulphur and is discarded.

The nickel/copper matte from the reverberatory furnaces is processed in converters which, unlike the copper circuit converters, produce a low iron and sulphur nickel/copper "Bessemer" matte, instead of a metallic product (the Bessemer matte is 77% nickel/copper/cobalt). The converters produce a large volume intermittent off-gas stream, averaging about 3% SO_2 by volume, which passes via hoods and flues to electrostatic precipitators, from which it is discharged to the atmosphere through the 381 m stack.

The converter off-gas contains 10.1% of the total sulphur in the ore.

Three of the fourteen converters in the nickel circuit have experimental tight-fitting, water-cooled hoods to improve the collection of the off-gas and reduce the amount of air mixed with the SO_2. These converters were fitted with double flue systems to permit the separation of strong and weak off-gas streams, the intent being to isolate the stronger gas for possible acid manufacture. Detailed information on the performance of these special hoods has yet to be provided by Inco Limited.

The liquid Bessemer matte is poured into moulds and allowed to cool slowly. During cooling, fairly large, discrete crystals of copper and nickel sulphides and a copper/nickel metallic alloy form. The cooled matte is crushed and transported to matte processing. The first steps in matte processing separate the copper and nickel sulphides and the copper/nickel metallic alloy (which is usually referred to simply as the "metallics"). The copper sulphide goes to the copper converters in the smelter, the metallics go to the Copper Cliff Nickel Refinery and the nickel sulphide is roasted in fluid bed roasters in the matte processing plant to produce nickel oxide.

The roasters (fluid bed) are the source of SO_2 emissions from matte processing. The roaster off-gas is 10% SO_2 by volume, which means that it is of sufficient strength for sulphuric acid manufacture. Nevertheless, the gas, which accounts for 2.6% of the sulphur in the ore, is emitted to the atmosphere via the 381 m stack.

The nickel circuit is currently the largest contributor to the total particulate emissions of 11,417 tonnes per year from the 381 m stack (Table 3.2). This circuit is therefore thought to offer the greatest potential for reduction in particulate emissions since it currently has the least degree of control.

The relative contributions of the copper and nickel circuits to the fugitive emissions of particulates and SO_2 from the smelter is presented in Table 3.1. In this instance, the nickel circuit is of less importance than the copper circuit.

3.2.3 Copper Cliff Nickel Refinery

The metallics sent to the nickel refinery are treated in top-blown rotary converters (TBRCs), which are different from the converters in the smelter. High-purity oxygen is blown onto the surface of the liquid melt in a rotating vessel. Sulphur is combusted to sulphur dioxide and metallic nickel is formed which, after further processing, is converted to nickel pellets, nickel powder and ferro-nickel powder. The off-gas stream is weak in SO_2 (averaging 2% by volume), representing 0.5% of the sulphur in the ore and is vented to the atmosphere via the 194 m IORP stack.

3.2.4 Iron Ore Recovery Plant (IORP)

The IORP is designed to process the nickel-bearing pyrrhotite concentrate to produce nickel oxide powder, iron ore pellets, and sulphuric acid. Essentially all of the sulphur in the concentrate is eliminated by roasting in fluid bed roasters. The off-gas, which is about 12% SO_2 by volume, is ducted to the sulphur products plant. This plant actually consists of three separate acid plants which have a combined capacity of 2,850 tonnes per day of acid. The off-gas is first cleaned, cooled and dried. The sulphur dioxide is then catalytically converted to sulphur trioxide (SO_3), which is absorbed in recycle acid to produce market grades of acid. Production in the past has reached almost 800,000 tonnes per year.

Sulphur contained in the acid amounts to 20.5% of the sulphur in the ore. The tail gas from the acid plant and any gas which by-passes the plant are the only sources of atmospheric emissions of SO_2 at the IORP. They account for about 2.5% of the total sulphur mined.

The calcine from the roasters is leached to produce a nickel solution and a residue of magnetite. Nickel oxide is manufactured from the solution by a hydrometallurgical process. Nickel oxide production at the IORP is 6,000 to 7,000 tonnes per year, or 4% to 5% of Inco's total nickel production at Sudbury (based on 1980 figures).

The process is also designed to produce iron ore pellets from the magnetite, but at present there is no market for iron ore pellets and the magnetite residue is disposed of as waste.

3.3 Summary of Emissions from the Present Process

A breakdown of the sources of SO_2, sulphuric acid, total particulate and trace metals at Inco for the period 1973 to 1981 in tonnes per year is presented in Table 3.2. The Inco 381 m stack is by far the largest point source of SO_2 and particulate emissions. The IORP 194 m stack also contributed substantial amounts to the emissions of total particulate, iron, copper and nickel. However, current contributions from the 194 m stack are expected to be lower than the 1973 to 1981 average due to the installation of additional electrostatic precipitators at the nickel refinery in 1980.

Low level fugitive SO_2 emissions from the Copper Cliff smelter represent about 1.4% of total SO_2 emissions from the smelter, averaging 12,000 tonnes per year during the period 1973 to 1981. These fugitive emissions have also been identified as an appreciable source of particulates and metals, especially copper.

While SO_2 emissions from the Sudbury operations are the focus of this report, particulate and trace metals emissions are also of concern. The accuracy of the measurements taken in determining particulate emissions is in the order of plus or minus 25%. The relationship of the emissions to overall production at the time the measurements were taken probably carries a greater uncertainty. Attribution of the emissions of particulates and metals to specific process sources is even less certain.

Important observations with respect to the disposition of sulphur, which arise from the above description of Inco's present process operations, include:

- The removal of additional sulphur during ore concentration, by separating and rejecting increased amounts of pyrrhotite with the gangue, would directly reduce the sulphur input to the smelter by 21.8% and decrease the amount of SO_2 produced in the smelter by 345 tonnes per day. Thus, the sulphur burden on subsequent SO_2 containment systems would be reduced, but about 2% of the nickel would be lost from the concentrate.

- About 85% of the remaining 78.2% sulphur which enters the smelter would be emitted to the atmosphere in the form of SO_2.

- The nickel and copper circuits in the Copper Cliff smelter account for 83% of the total SO_2 emitted to the atmosphere; the remaining emissions come from matte processing, the Copper Cliff nickel refinery and the IORP.

- Slightly more than one-half of the smelter's SO_2 emissions originate in the nickel and copper converters. The nickel converters account for about 57% of the total converter emissions. The flow of gas from the converters, especially from the nickel converters, is intermittent, variable and low in concentration, making it difficult to capture and treat the SO_2.

- The multi-hearth roasters and reverberatory furnaces produce large quantities of off-gas which have low concentrations of SO_2. These units are based on 50-year old technology.

- Many of the steps in the smelting process, especially those which involve the transfer of molten material, result in SO_2 emissions into the workplace. These so-called fugitive emissions are relatively small in quantity, but are nonetheless of concern with respect to the workroom environment.

- The IORP now functions principally as a sulphuric acid plant because there is no demand for the iron oxide pellets it originally produced. The nickel oxide recovered in the plant is a small proportion of Inco's nickel production at Sudbury (4% to 5%) and is of a special acid-soluble quality.

3.4 Opportunities for Further Reductions in Sulphur Dioxide Emissions

The principal components which can be considered for further SO_2 emission reductions at Inco are:

A. Increased sulphur rejection in the milling process.

B. Smelting process changes to increase the proportion of SO_2 contained in continuous gas streams of relatively strong SO_2 concentration, as opposed to weak intermittent gas streams which are difficult and costly to collect and treat.*

C. Treatment of strong gas streams to remove SO_2.

D. Treatment of residual weak gas streams to remove SO_2.

E. Reduction of fugitive emissions.

A number of technologies which might be employed as part of a program to reduce SO_2 emissions at Inco have been examined. The first step in this examination was the development of a list of potentially applicable abatement technologies. The list, which is divided into five categories, is given in Appendix 3.1.

The next step involved reviewing the list in order to eliminate from detailed investigation all technologies which did not demonstrate any advantages with respect to SO_2 control when compared with other technologies assessed as being more readily applicable to Inco's operations. In addition, technologies which would require more than five years of development work before their effectiveness in processing the Sudbury ores could be determined were dropped from the list. Processes which would achieve only marginal gains in SO_2 reduction at very high costs were also eliminated at this stage.

* Gas streams containing less than about 4% SO_2 by volume are classified as weak gas streams. The basis of this classification is that effective processing of SO_2 gases in conventional acid plants requires concentrations greater than 4%.

The abatement technologies which met the general selection criteria outlined above were considered as candidates for inclusion in one of the overall abatement programs, which are described in Chapter 4.

The conclusions of the review of abatement technologies in each of the five categories are summarized below.

3.4.1 Sulphur Rejection During Ore Concentration

The current nickel concentrate contains about 11% nickel, 2% copper and 30% sulphur (see Figure 3.3). The changes to the pyrrhotite rejection process which are underway at Inco would produce a concentrate of 15% nickel, 1.4% copper and 31.7% sulphur. Assuming the same level of nickel production as in 1980, this increase in nickel concentration implies that slightly more than one-fifth of the sulphur contained in the 1980 concentrate feed to the smelter would be rejected before it enters the smelter. This is equivalent to a reduction in SO_2 emissions of 345 tonnes per day. Production of the richer concentrate would incur a nickel loss of 2% prior to smelting, as compared with the 1980 practice.

The possibility of achieving even greater levels of sulphur rejection from the nickel concentrate was reviewed, but the lack of available data on the relationships between the qualities and quantities of the various products from Inco's ores prevented the drawing of conclusions about the implications of yet greater rejection, and thus, this option is not considered further.

The copper concentrate produced in the existing milling process is high grade (30% copper) and further upgrading by increased sulphur rejection would have the effect of increasing the copper burden in the nickel circuit. Such a change would be counter-productive in its impact on the circulating sulphur loads between the copper and nickel circuits and in moving sulphur out of the section (i.e. the copper circuit) of the smelter which already produces a strong SO_2 off-gas.

3.4.2 Pyrometallurgical Processes Yielding Strong SO_2 Off-Gas Streams

Copper smelting technology which results in the emission of strong SO_2 gas streams is well developed, however its application to nickel smelting has not been explored in detail. Inco has in operation an oxygen flash smelting process for copper concentrates which produces off-gases with very high (70% to 80%) SO_2 concentrations. Considerable effort has been devoted to evaluating this process for the treatment of Sudbury's nickel concentrates.

Although three other technologies have been in use around the world, none possesses clear-cut advantages over the Inco flash smelting process. The most promising for use at Copper Cliff is the Outokumpu flash furnace which uses oxygen-enriched air, instead of oxygen, and has a different geometry and gas flow pattern. The Noranda process, using oxygen-enriched air in a cylindrical furnace fed with copper concentrate and coal fines, produces a high grade matte as do the other oxygen-using furnaces.

The major metallurgical problem with the application of these technologies to the Inco smelter lies in the difficulty of obtaining high matte quality. The short converting operation to complete iron removal is likely, with the Sudbury ores, to be too short for adequate vaporization of the volatile impurities (e.g. arsenic) which are present in the ores and the furnace matte. In addition, the furnace slag contains recoverable metals which require a slag cleaning operation.

The fourth process to be considered is the Mitsubishi continuous smelting process which offers the advantage of producing a steady stream of strong SO_2 gas. It also allows a continuous steady stream of molten material to be transferred under the influence of gravity and avoids the need for transfer of hot sulphur-containing products, which release sulphur dioxide, in open ladles. Reduced emissions of sulphur dioxide into the plant atmosphere result in improved working conditions. However, the metallurgy of the process has not been fully explored with respect to the Sudbury ores while the energy intensive aspect of the process results in high operating costs.

The Inco flash smelting process for nickel concentrates, the development of which was halted in favour of work on the roast/reduction smelting process, is the best developed of the processes, but may still require improvements before it could be implemented at Copper Cliff. Any of these options would also demand completely new facilities if they were to be introduced at Copper Cliff.

Other emerging technologies would require five to ten years of development work before they could be commercialized. They have, therefore, not been selected for detailed evaluation.

In principle, the processes used for copper smelting might be used for nickel concentrates, but the slag metal content, the heat release rate and the achievable degree of sulphur removal are some of the factors which would require investigation before a commercial system is available. Only two of these systems, the Outokumpu and the Inco flash smelting processes, are considered to have been developed to a stage where their utilization at Copper Cliff warrants further consideration for the nickel circuit.

Other technologies available for the nickel circuit, which give rise to strong continuous gas streams, have been developed by Inco. These are developments from the fluid bed roasting technology previously used for copper smelting and applied at Falconbridge for copper/nickel smelting.

Emissions from the roaster are high in sulphur dioxide content and roasting is therefore carried out to an extended degree, to remove as much sulphur as is reasonable, and the calcine produced is then passed to an electric smelting furnace.

In the electric furnace, the calcine is smelted and a dilute SO_2 stream is produced. At the high temperatures of the furnace, iron is converted to iron oxide and a relatively large quantity of slag (iron silicate) is formed. The slag carries with it dissolved nickel and copper oxides in quantities too high to be acceptable. A slag cleaning process is thus required to recover the metal content of the slag. In addition, it is necessary to reduce these metal losses by limiting the time of treatment and the SO_2 formation, permitting additional sulphur to pass to the converters whence it is released as a dilute SO_2 gas stream.

A further development of this process is "roast/reduction" smelting, in which the electric furnace is operated under reducing conditions brought about by the introduction of carbon with the calcine. The production of iron oxide, and therefore, of slag, is much reduced since the iron remains in the metallic state and does not form silicates with the flux. As a result, it is possible to extend the roasting and smelting processes to leave a high grade matte (75% metals) while reducing emissions from the furnace and from the subsequent converter operations.

For copper and nickel converting, Pierce-Smith converters (the type already in use) are selected for inclusion in the abatement programs in conjunction with improved hood systems which would increase the concentration of SO_2 in the off-gas (by reducing the volume of dilution air) and allow treatment in either an acid plant or a weak gas treatment plant.

In the options studied for Inco, the copper converter off-gases are directed to acid plants while the nickel converter off-gases are either emitted directly to the stack or treated in a weak gas treatment plant. In the case of the Inco roast/reduction process for nickel concentrate, where the nickel converter SO_2 emissions are low in quantity and in concentration, treatment in a weak gas treatment plant is the most feasible option. However, in the flash smelting option for nickel concentrate, close-hooding, blending with strong SO_2 streams and directly converting the converter off-gases to sulphuric acid in an acid plant could be considered.

3.4.3 Methods of Sulphur Dioxide Recovery from Off-Gas Streams (Strong and Weak)

All of the methods listed in Table 3.3 are considered to be adequately proven in industrial applications and all are considered as potential candidates for the abatement programs at Inco.

3.4.4 Hydrometallurgical Processes for Copper and Nickel Recovery

Any of these processes would require complete replacement of the existing copper or nickel smelting or matte treatment processes at Copper Cliff. It was concluded that such replacement would not be justified, based on technical and economic considerations.

3.5 Conclusions

Examination of the technologies available has indicated that effective sulphur fixation in the nickel circuit requires replacement of the multi-hearth roasters and reverberatory furnaces with processes which give rise to concentrated SO_2 off-gas streams. The technologies selected for further examination, and which will be discussed in detail in the next Chapter, are:

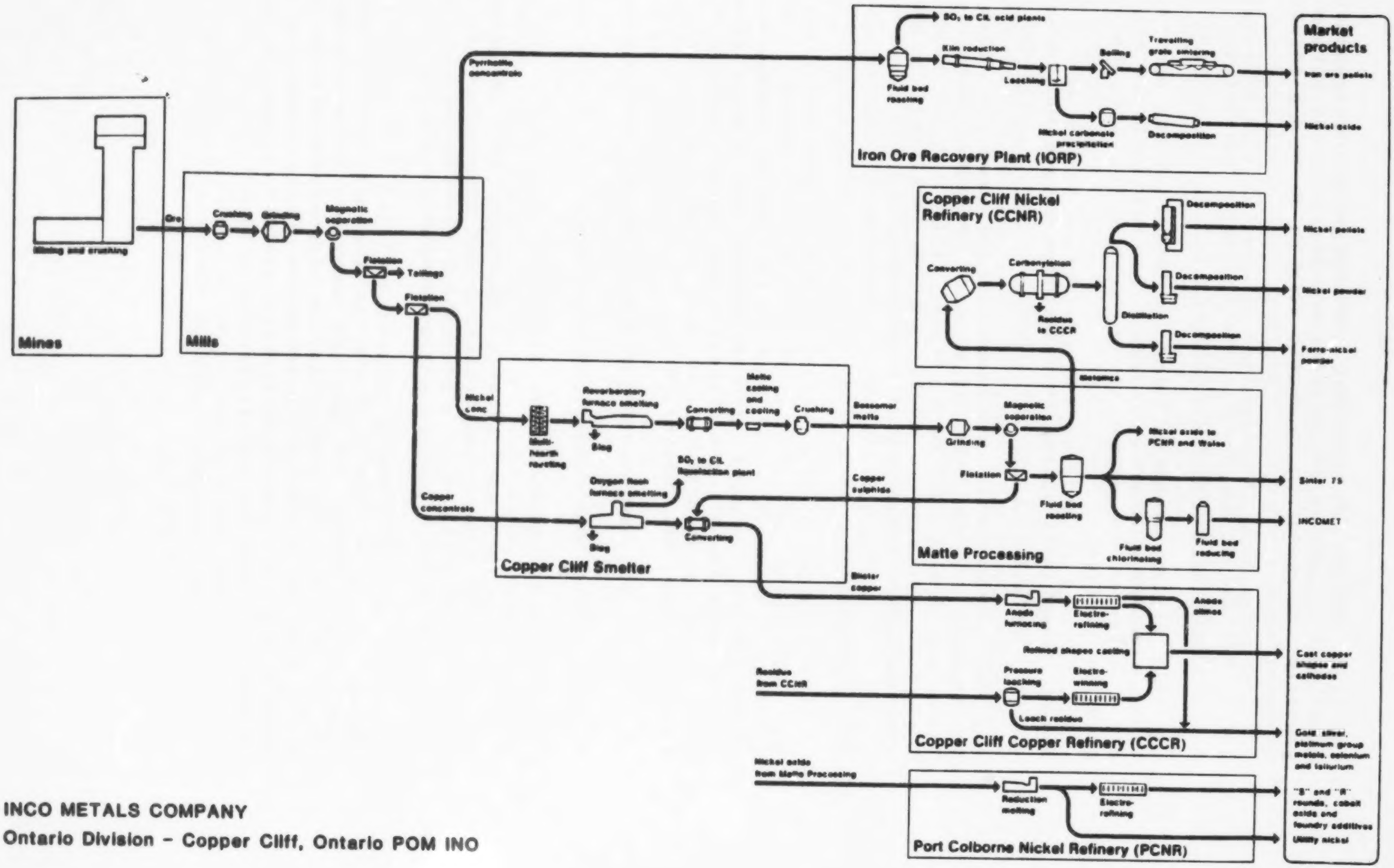
- fluid bed roasting/electric furnace smelting;
- Inco roast/reduction smelting;
- Inco and Outokumpu flash smelting.

In addition, more detailed attention will be given to the question of weak gas treatment and the use of the IORP acid plant as well as to a proposal for using the IORP fluid bed roasters for nickel/copper concentrate roasting.

With any of these processes selected for examination, there will be a need to consider the acid plant capacity required and the use of weak gas recovery systems for dilute SO_2 collection. The latter may be regenerable systems which give rise to concentrated recovered SO_2 streams for acid manufacture or non-regenerable systems where a waste product, which will require disposal, is formed.

FIGURE 3.1

SUDBURY OPERATIONS FLOWSHEET (1979)

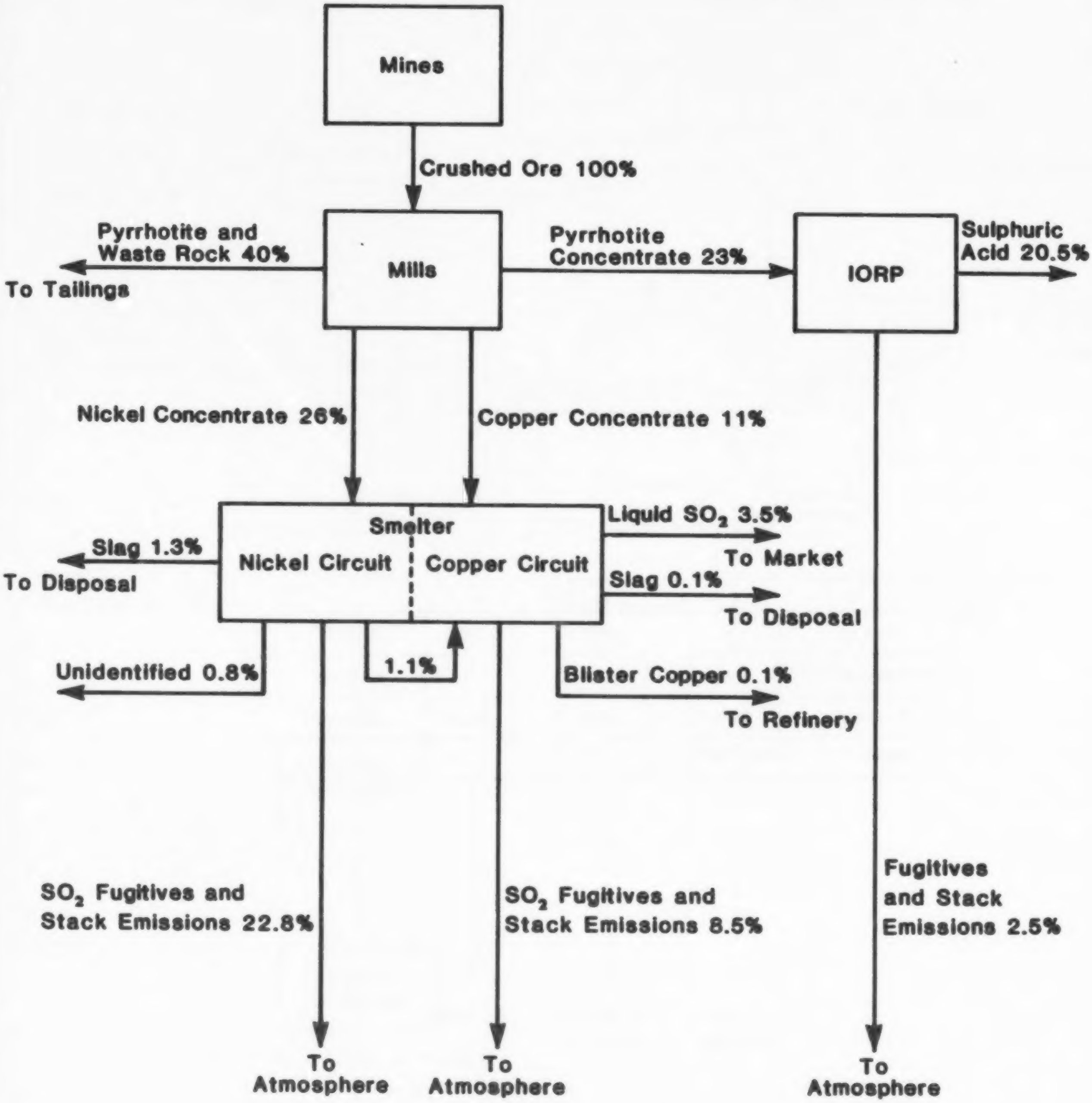

Mines
Mining and crushing
Ore
Mills
Crushing
Grinding
Magnetic separation
Flotation
Tailings
Flotation
Pyrrhotite concentrate
Nickel conc
Copper concentrate
Iron Ore Recovery Plant (IORP)
SO_2 to C.C. acid plants
Fluid bed roasting
Kiln reduction
Leaching
Boiling
Travelling grate sintering
Nickel carbonate precipitation
Decomposition
Copper Cliff Smelter
Multi-hearth roasting
Reverberatory furnace smelting
Slag
Converting
Matte casting and cooling
Crushing
Oxygen flash furnace smelting
SO_2 to C.C. liquefaction plant
Slag
Converting
Bessemer matte
Copper sulphide
Blister copper
Copper Cliff Nickel Refinery (CCNR)
Converting
Carbonylation
Residue to CCCR
Distillation
Decomposition
Decomposition
Decomposition
Metallics
Matte Processing
Grinding
Magnetic separation
Flotation
Fluid bed roasting
Nickel oxide to PCNR and Wales
Fluid bed chlorinating
Fluid bed reducing
Copper Cliff Copper Refinery (CCCR)
Anode furnacing
Electro-refining
Anode slimes
Refined shapes casting
Residue from CCNR
Pressure leaching
Electro-winning
Leach residue
Nickel oxide from Matte Processing
Port Colborne Nickel Refinery (PCNR)
Reduction melting
Electro-refining
Market products
Iron ore pellets
Nickel oxide
Nickel pellets
Nickel powder
Ferro-nickel powder
Sinter 75
INCOMET
Cast copper shapes and cathodes
Gold, silver, platinum group metals, selenium and tellurium
"S" and "R" rounds, cobalt oxide and foundry additives
Utility nickel

INCO METALS COMPANY

Ontario Division - Copper Cliff, Ontario POM INO

FIGURE 3.2

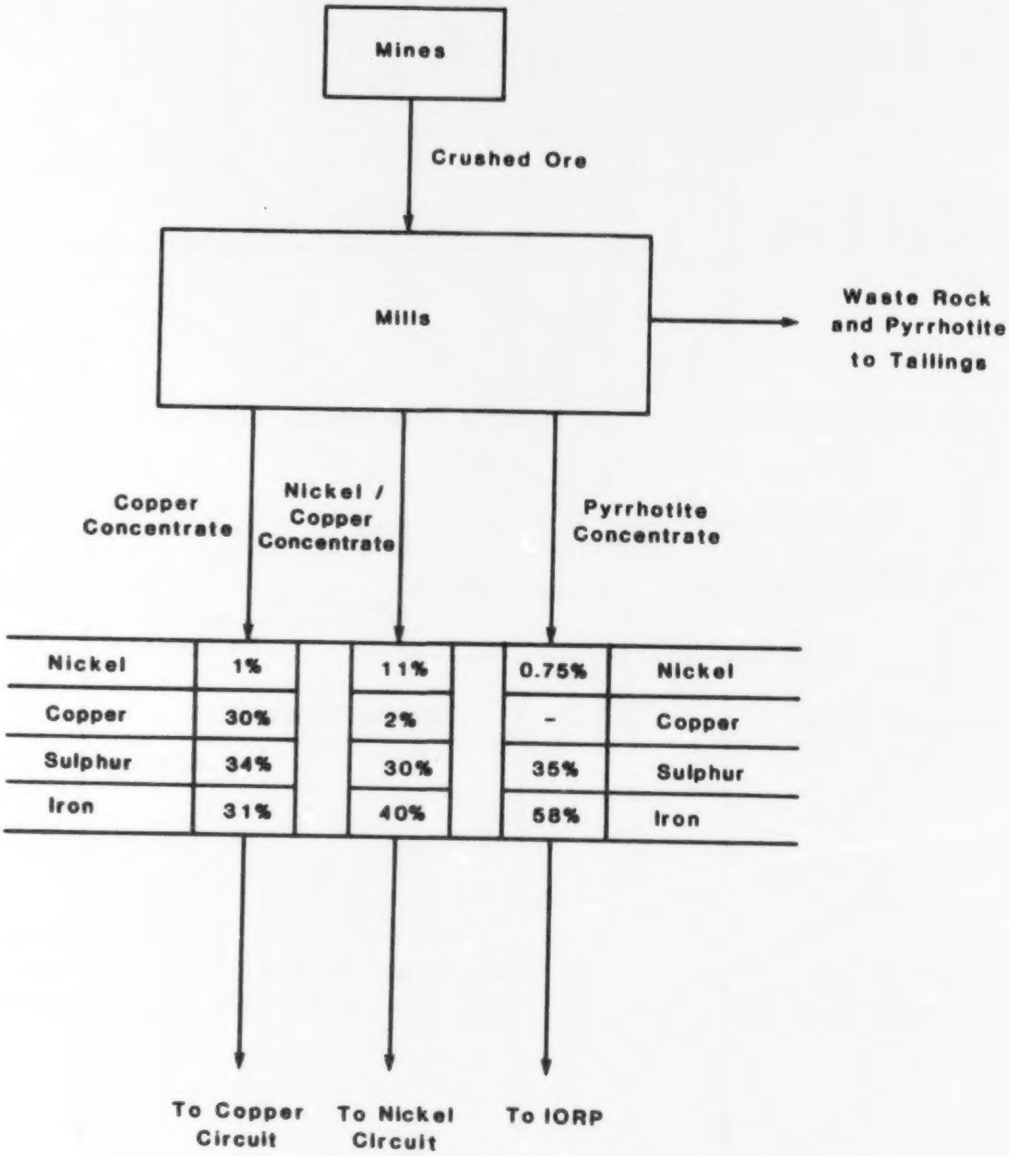
SIMPLIFIED SULPHUR BALANCE - EXISTING (1980) INCO OPERATIONS AT SUDBURY*


Mines
Crushed Ore 100%
Pyrrhotite and Waste Rock 40%
To Tailings
Mills
Pyrrhotite Concentrate 23%
IORP
Sulphuric Acid 20.5%
Nickel Concentrate 26%
Copper Concentrate 11%
Smelter
Nickel Circuit
Copper Circuit
Slag 1.3%
To Disposal
Liquid SO2 3.5%
To Market
Slag 0.1%
To Disposal
Unidentified 0.8%
1.1%
Blister Copper 0.1%
To Refinery
SO2 Fugitives and Stack Emissions 22.8%
SO2 Fugitives and Stack Emissions 8.5%
Fugitives and Stack Emissions 2.5%
To Atmosphere
To Atmosphere
To Atmosphere

*Percentage Sulphur in Mined Ore

FIGURE 3.3

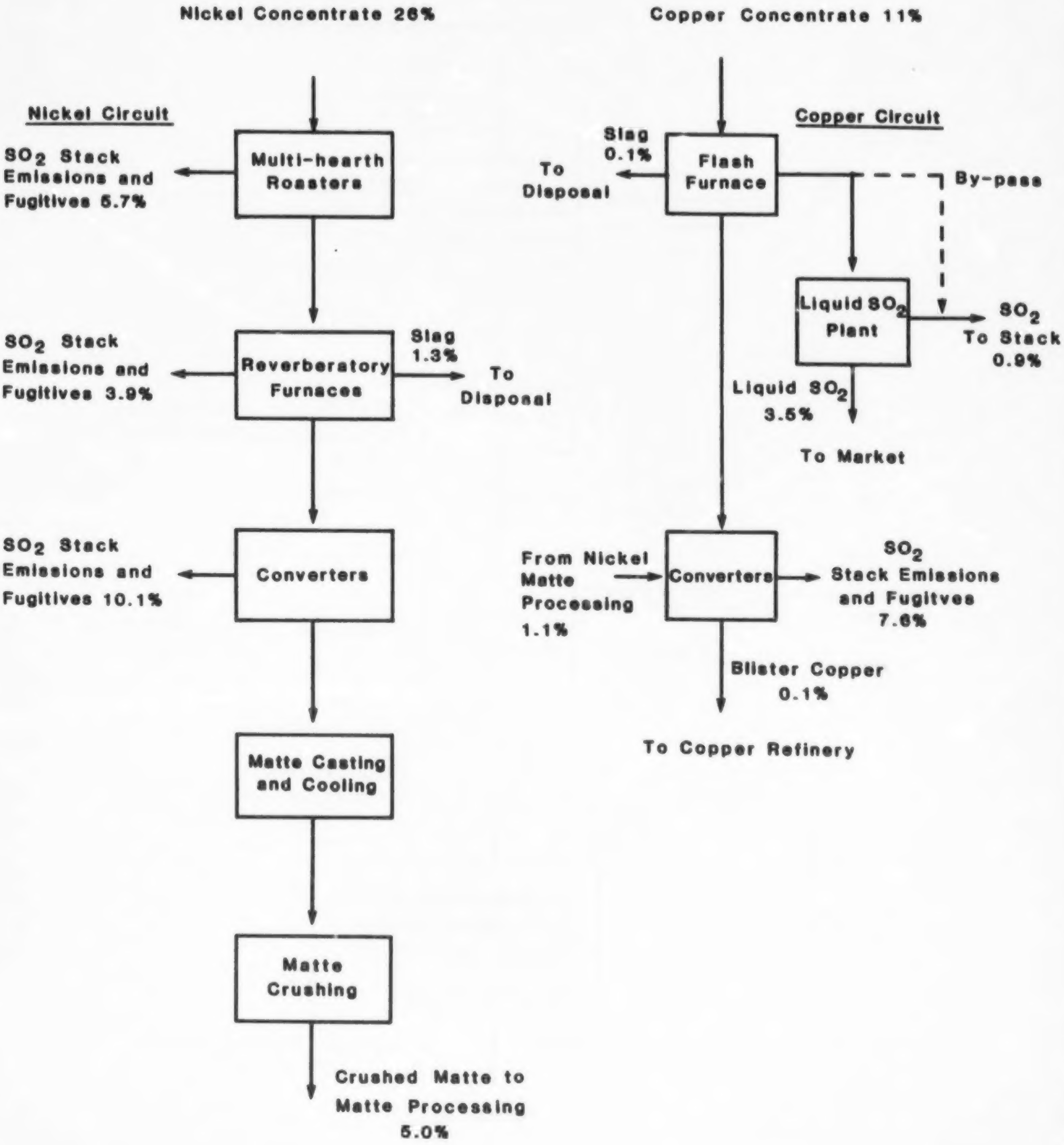
COMPOSITION OF INCO ORE CONCENTRATES (1980)


Mines
Crushed Ore
Mills
Waste Rock and Pyrrhotite to Tailings
Copper Concentrate
Nickel / Copper Concentrate
Pyrrhotite Concentrate
To Copper Circuit
To Nickel Circuit
To IORP

	Copper Concentrate	Nickel / Copper Concentrate	Pyrrhotite Concentrate	
Nickel	1%	11%	0.75%	Nickel
Copper	30%	2%	-	Copper
Sulphur	34%	30%	35%	Sulphur
Iron	31%	40%	58%	Iron

FIGURE 3.4

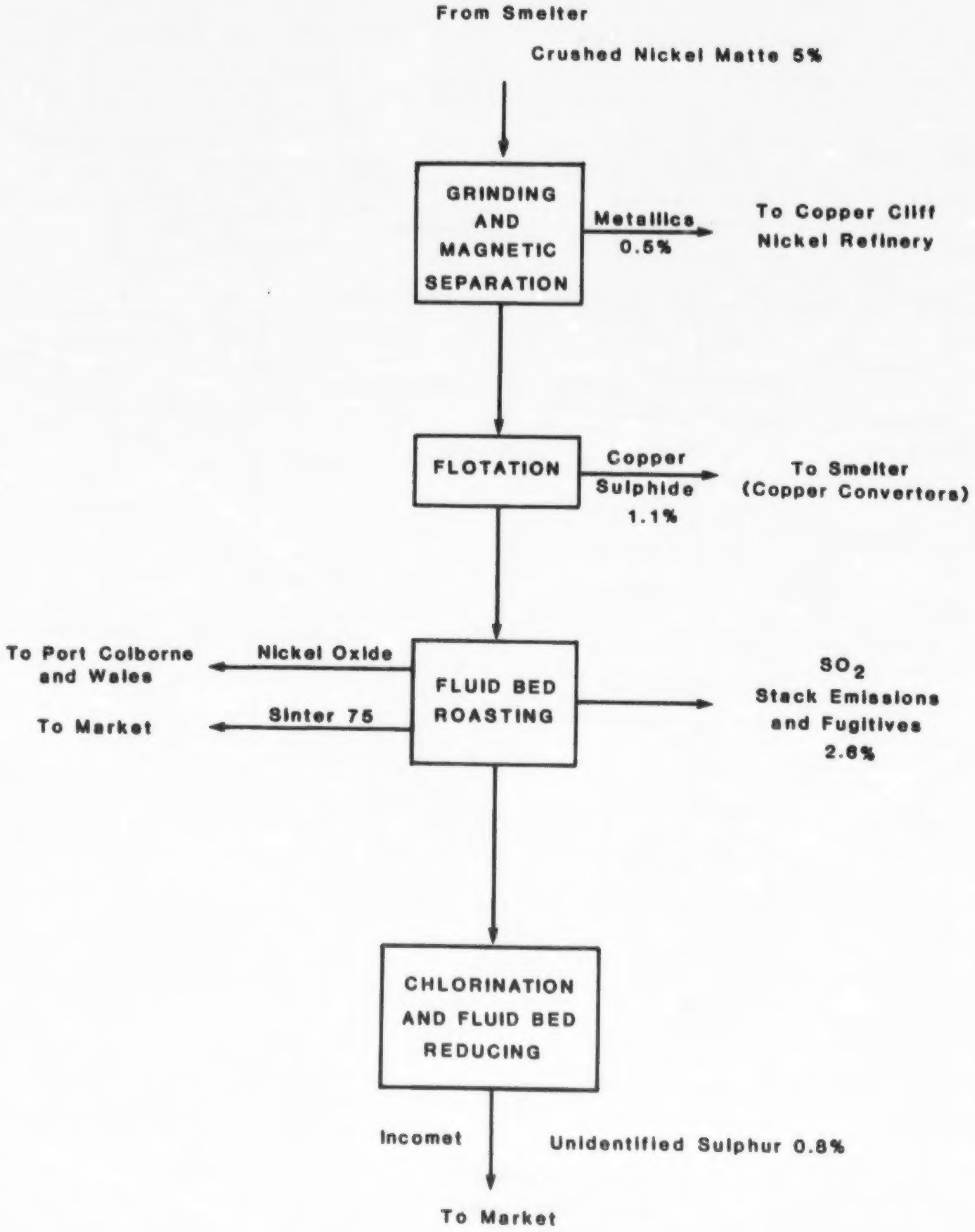
SIMPLIFIED SULPHUR BALANCE-COPPER CLIFF SMELTER *


Nickel Concentrate 26%
Copper Concentrate 11%
Nickel Circuit
Copper Circuit
SO2 Stack Emissions and Fugitives 5.7%
Multi-hearth Roasters
SO2 Stack Emissions and Fugitives 3.9%
Reverberatory Furnaces
Slag 1.3%
To Disposal
SO2 Stack Emissions and Fugitives 10.1%
Converters
Matte Casting and Cooling
Matte Crushing
Crushed Matte to Matte Processing 5.0%
Slag 0.1%
To Disposal
Flash Furnace
By-pass
Liquid SO2 Plant
SO2 To Stack 0.9%
Liquid SO2 3.5%
To Market
From Nickel Matte Processing 1.1%
Converters
SO2 Stack Emissions and Fugitves 7.6%
Blister Copper 0.1%
To Copper Refinery

* Percentage Sulphur of the Mined Ore

FIGURE 3.5

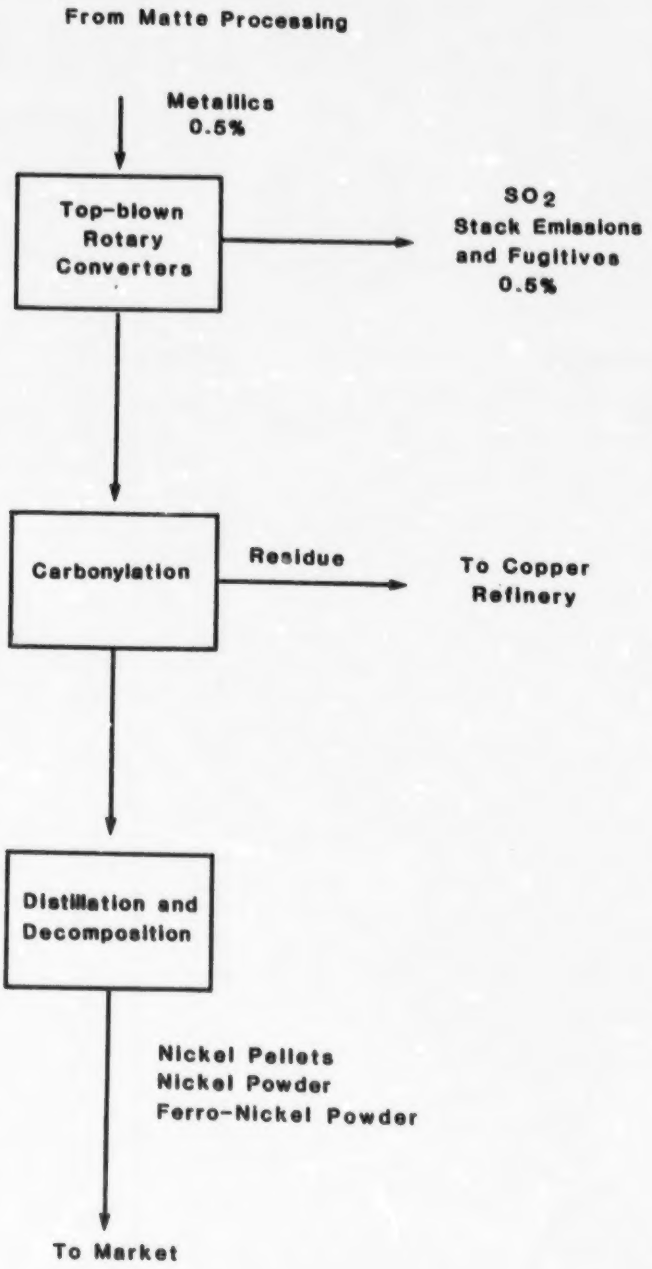
SIMPLIFIED SULPHUR BALANCE -COPPER CLIFF MATTE PROCESSING*


From Smelter
Crushed Nickel Matte 5%
GRINDING AND MAGNETIC SEPARATION
Metallics 0.5%
To Copper Cliff Nickel Refinery
FLOTATION
Copper Sulphide 1.1%
To Smelter (Copper Converters)
To Port Colborne and Wales
Nickel Oxide
To Market
Sinter 75
FLUID BED ROASTING
SO2 Stack Emissions and Fugitives 2.6%
CHLORINATION AND FLUID BED REDUCING
Incomet
Unidentified Sulphur 0.8%
To Market

*Percentage Sulphur in Mined Ore

FIGURE 3.6

SIMPLIFIED SULPHUR BALANCE-COPPER CLIFF * NICKEL REFINERY


From Matte Processing
Metallics 0.5%
Top-blown Rotary Converters
SO_2 Stack Emissions and Fugitives 0.5%
Carbonylation
Residue
To Copper Refinery
Distillation and Decomposition
Nickel Pellets
Nickel Powder
Ferro-Nickel Powder
To Market

* Percentage Sulphur of the Mined Ore

TABLE 3.1

RELATIVE CONTRIBUTION FROM VARIOUS SOURCES TO LOW LEVEL SO_2 AND PARTICULATE EMISSIONS FROM THE INCO COPPER CLIFF SMELTER*

EMISSION SOURCE	RELATIVE CONTRIBUTION (%) SO_2	RELATIVE CONTRIBUTION (%) PARTICULATES
COPPER CONVERTERS	41	70
COPPER FLASH FURNACE	17	3
NICKEL REVERB. FURNACES	25	9
NICKEL CONVERTERS	8	9
MISCELLANEOUS	9	9
TOTAL	100	100

* Source of data: Feasibility of Controlling Low Level Emissions from the Copper Cliff Smelter Complex, Inco Metals Company, Ontario Division - Process Technology Report No. 047.21, December 15, 1981.

TABLE 3.2

AVERAGE YEARLY EMISSIONS (TONNES) OF MAJOR POLLUTANTS IN THE SUDBURY BASIN FROM INCO FOR THE PERIOD 1973 TO 1981

SOURCE	SO_2*	SULPHURIC ACID	TOTAL PARTICULATE	IRON	COPPER	NICKEL	LEAD	ARSENIC
381 Meter Smelter Stack**	885,667	7,270	11,417	990	245	228	184	114
194 Meter IORP Stack+	54,568	1,664	2,380	643	171	226	6	4
Copper Cliff Smelter (Low Level)0	12,000	88	586	70	242	31	0.6	0.1
TOTAL	952,235	9,022	14,383	1,703	658	485	190.6	118.1

* SO_2 emission estimates for the 381 m and 194 m stacks were obtained from mass balance calculations.

** Emissions of total particulate, iron, copper and nickel were calculated from correlations with SO_2 emissions. Oxides of nitrogen emissions expressed as NO_2 are about 3,281 tonnes per year.

+ The sulphuric acid, total particulate and trace metal emission rates were calculated from stack measurements performed in 1977.

0 Emission rates for all substances determined from measurements conducted in 1978 and 1979 and prorated to other years on the basis of production.

Source of Data: Ozvacic, V., Emissions of Sulphur Oxides, Particulates and Trace Elements In The Sudbury Basin, Ontario Ministry of the Environment, Sudbury Environmental Study, Report No. SES/008 (1982).

APPENDIX 3.1

ABATEMENT TECHNOLOGIES REVIEWED

A. SULPHUR REJECTION DURING ORE CONCENTRATION

	Process	Status
1.	Upgrading of Copper Concentrate	No advantage
2.	Inco Pyrrhotite Rejection Process	Soon to be installed
3.	Additional Pyrrhotite Rejection	Speculative

B. PYROMETALLURGICAL PROCESSES YIELDING STRONG SO_2 OFF-GAS

	Process	Status
	Copper Smelting Processes*	
1.	Inco Oxygen Flash Smelting	Available Established at Copper Cliff smelter
2.	Outokumpu Oxygen - Enriched Air Flash Smelting	Available Established in Finland & Japan
3.	Outokumpu Hot Air Flash Smelting Process	Available Approximately 20 units in operation around the world
4.	Noranda Process	Available Established by Noranda & Kennecott

* Smelter technologies suitable for copper smelters may not be suitable for nickel/copper processing because of differing metallurgies and impurity removal problems. Inco especially uses ores with high volatile metal content.

Converter emission control hooding techniques are less easily applied to nickel converters since higher temperatures and extensive metal splashing create mechanical problems for hood removal and replacement operations.

APPENDIX 3.1 (continued)

ABATEMENT TECHNOLOGIES REVIEWED

	Process	Status
5.	Mitsubishi Continuous Smelting Process	Available Established in Japan A unit has been started up at the Kidd Creek smelter in Timmins
6.	Oxygen Sprinkle Smelting	Emerging Process
7.	AMAX Fluid Bed Dead Roasting/Blast Furnace Reduction Process	Emerging Process
8.	Brixlegg Process	Emerging Process
9.	Q-S Oxygen Process	Emerging Process
10.	KHD Contop Process	Emerging Process
Nickel and Copper/Nickel Smelting Processes		
11.	Fluid Bed Roasting/Electric Furnace Smelting	Available Established at Thompson and by Falconbridge
12.	Inco Roast/Reduction Smelting	Under development Advanced
13.	Inco Oxygen Flash Smelting	Available Commercially operated for trial periods (for copper/nickel concentrates)

APPENDIX 3.1 (continued)

ABATEMENT TECHNOLOGIES REVIEWED

	Process	Status
14.	Outokumpu Flash Smelting	Available Established in Australia, Botswana, Finland and the USSR
Copper and Nickel Matte Converting Processes		
15.	Pierce-Smith Converting of Copper Matte	Available Established
16.	Pierce-Smith Converting of Nickel Matte	Available Established
17.	Mitsubishi Converting (used for copper only to date)	Emerging process for application as independent conversion process
18.	Hoboken Converting (used for copper only to date)	Available Established in Arizona, Chile, Poland, Belgium

C. METHODS OF SULPHUR DIOXIDE RECOVERY FROM STRONG GAS STREAMS

	Process	Status
1.	Production of Elemental Sulphur	Available Advanced
2.	Production of Liquid Sulphur Dioxide	Available Established
3.	Production of Sulphuric Acid	Available Established

APPENDIX 3.1 (continued)

ABATEMENT TECHNOLOGIES REVIEWED

D. METHODS OF SULPHUR DIOXIDE RECOVERY FROM WEAK GAS STREAMS

Process	Status
Regenerative Processes	
1. Magnesium Oxide Process	Available Established
2. Citrate (Flakt-Boliden) Process	Available Advanced (but not yet in commercial use)
3. Ammonia (Cominco) Process	Available Established (but not yet in commercial use)
4. Sodium Sulphite/Bisulphite (Wellman-Lord) Process	Available Established (but not yet in commercial use)
5. Dimethylaniline (DMA) Process	Available Advanced (but not yet in commercial use)
Non-Regenerative Processes	
6. Lime/Limestone Process	Available Established
7. Double Alkali Process	Available Established

APPENDIX 3.1 (continued)

ABATEMENT TECHNOLOGIES REVIEWED

E. HYDROMETALLURGICAL PROCESSES FOR COPPER AND NICKEL RECOVERY

Process	Status
Copper Recovery	
1. Duval Cupric Chloride-Leach/ Electrowin Process (Clear Process)	Available Early
2. Cyprus Copper Process (CYMET)	Emerging
3. Sherritt-Cominco Process	Emerging
4. Arbiter Ammonia-Oxygen Leach Process	Available Early
5. Roast-Leach-Electrowin Process	Available Early

Process	Status
Nickel Recovery	
6. Sherritt Gordon Ammonia-Air Leach Process	Available Early
7. Outokumpu (AMAX) Copper Sulphate Matte Load Process	Available Early
8. Falconbridge Chlorine/ Hydrochloric Acid Matte Leach Process	Available Early

4. ABATEMENT PROGRAMS - INCO LIMITED

Abstract

A number of different abatement programs are developed for illustrative purposes from various combinations of the technologies described in Chapter 3.

The programs are described and assessed with respect to their capability of reducing emissions of sulphur dioxide, their costs, their production of wastes and/or marketable by-products and their availability for implementation.

The major process options chosen are:

- modifications to the copper circuit putting strong SO_2 streams to acid plants (CCM);
- Inco's roast/reduction smelting on the nickel circuit (RRS);
- Outokumpu flash furnace smelting on the nickel circuit (OFF);
- roast/reduction smelting using the IORP (IRRA);
- non-regenerative weak gas scrubbing of the IORP off-gases (IORP).

To the first three of these, it is possible to add either regenerative or non-regenerative weak gas treatment systems which, without the major options being installed, would not be feasible. The regenerative process chosen for purposes of illustration at Inco is the Wellman-Lord process in which sodium sulphite solution is used as the absorbing liquid from which the SO_2 is stripped by heating and passed to the sulphuric acid plants. The non-regenerative system selected is the Davy Saarberg-Hoelter process using limestone in slurry form to absorb the SO_2 and produce a waste sludge (gypsum) for disposal.

It is assumed throughout this report that increased pyrrhotite rejection will be employed by Inco and the starting point for estimating emission reductions assumes a base case of 280 million lb per year nickel production resulting in smelter emissions of 1,766 tonnes of SO_2/calendar day.

Of the process change options selected, modifications to the copper circuit would offer the most rapid opportunity for emission reductions, but would leave smelter emissions at more than 1,000 tonnes of SO_2/day.

Nickel circuit changes would reduce smelter SO_2 emissions to about 850 tonnes/day (RRS) or 930 tonnes/day (OFF). When these are combined with copper circuit

modifications, the total smelter emissions could be reduced to below 300 tonnes/day. To obtain further reductions, weak gas treatment is essential and, when combined with modifications to both circuits, total smelter emissions could be reduced to less than 30 tonnes/day.

Control of emissions from the IORP has also been considered. The use of weak gas treatment processes would permit reductions of 90%, thereby, lowering emissions to 19 tonnes/day.

An alternative option (IRRA), whereby the IORP equipment is used for roast/reduction smelting of nickel concentrate only, has been proposed by Inco. The estimated cost of $430 million is believed to be more realistic than other estimates since it included factors which were not included in the Task Force estimates. Sulphur dioxide emission reductions of 1,064 tonnes/day include 100 tonnes/day reduction in the IORP emissions. The resultant smelter emissions at Copper Cliff are 802 tonnes/day.

In addition, the intensive cleaning of off-gas streams prior to manufacturing sulphuric acid and additional cleaning of weak gas streams, which occurs during the SO_2 absorption, result in the reduction of particulate emissions. Despite a lack of detailed information about particulate emissions, their metal content and the degree of control which could be effected, it is thought that an overall reduction of about 75% might be achieved; of this total value, containment of between 55% and 75% of the fugitive particulate emissions might be expected as a result of the collection of off-gases from such sources as the converters.

Capital costs (expressed in January 1982 Canadian dollars) for these processes range from $75 million for copper circuit modifications to over $500 million for full control of both (copper and nickel) circuits and associated weak gas streams.

These cost estimates, limited by imposed constraints, are probably low. Additional costs of up to $300 million for changes implemented in the existing smelter are believed to be likely.

Operating costs have been estimated for the programs selected for review. They are summarized in Tables 4.2 and 4.3 and range from a savings of $25 million per year for the IORP roast/reduction smelting option to a maximum increase of $11.2 million per year (January 1982 Canadian dollars), based on an estimated operating cost for the Copper Cliff smelter of $57 million for 280 million lb per year nickel produced. Based upon this review of candidate technologies, combinations of abatement options identified as technically feasible are provided in Appendix 4.1 for subsequent analysis.

4.1 Introduction

4.1.1 Abatement Program Concept

The abatement programs selected in Chapter 3, which could be implemented employing one or more of the candidate abatement technologies to reduce SO_2 and other emissions at Inco, are described. These are not the only possible combinations of technologies; others could be developed, but the choices presented here are the outcome of directives given by the Task Force. These directives were essentially as follows:

- describe means by which SO_2 emissions at the Inco Copper Cliff smelter could be reduced significantly below the level of 1,770 tonnes/day (1,950 tons/day*) within a relatively short period of time, while maintaining the IORP emissions below 227 tonnes/day (250 tons/day*);
- describe how further increments of SO_2 reduction could be achieved down to or below 360 tonnes/day, if such levels are achievable with the candidate technologies.

In this Chapter, each abatement program is described in terms of its:

- impact on emissions of SO_2, particulates and other pollutants;
- capital and operating costs (expressed in January 1982 Canadian dollars);
- length of time required for development, engineering and construction;
- production of potentially marketable by-products, e.g. sulphuric acid;
- impact on other waste discharges from the process operations (e.g. tailings, slag, unmarketable by-products) and on waste disposal costs.

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* These are the limits set for the smelter by O.Reg 301(R.R.O.1980)) and by a Control Order initially made on the IORP in 1973.

Subsequent Chapters deal with the environmental, socio-economic and financial impacts which would result from implementation of the abatement programs.

4.1.2 Principal Assumptions Underlying All Abatement Programs

Inco's modified pyrrhotite rejection process is expected to be installed in the Copper Cliff Mill by the end of 1982. Based upon data provided by Inco, it was calculated that this would enable Inco to meet the SO_2 emission limit of 1,770 tonnes/working day which comes into effect in 1983. Therefore, this modified process has been included as a component of the base case from which further SO_2 emission reductions are calculated.

The SO_2 emitted from Inco's operations is directly proportional to the level of production. Therefore, in describing and comparing abatement programs, it was essential to consistently use a reference level of production. All new processes and equipment sizes in the abatement programs and all emission levels have been related to this reference level. The level selected and used for Inco in this report, unless otherwise indicated, is a nickel production rate of 280 million lb per year.*

A summary of the emissions and the costs associated with each program is given in Tables 4.1, 4.2 and 4.3. SO_2 emission levels of between 1,021 and 1,146 tonnes/day can be achieved by modification to the copper circuit, but to reduce emissions to below the target level of 363 tonnes/day (400 tons/day), extensive changes to the nickel circuit must also be included. Options considered acceptable would achieve emissions of 243 or 297 tonnes/day and these options could result in further reductions to 24 or 30 tonnes/day if weak gas treatment were added.

Estimates of the capital and operating costs for each major abatement program are given in Tables 4.2 and 4.3. All costs are expressed in January 1982 Canadian dollars. The capital cost estimates are based on conceptual plant arrangements, lists of major equipment and budget price quotations for selected plant or equipment items. In Table 4.3 and Figure 4.9, additional combinations are listed, together with cost information.

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* This is equivalent to 825,000 tonnes of nickel concentrate containing 15% nickel. It is also assumed that 400,000 tonnes of copper concentrate enter the smelter.

An allowance was made for construction field indirect costs, engineering and construction management fees. Also, a contingency (undefined costs) item was included in the estimates.

The conceptual nature of the engineering studies which support the cost estimates and the limited information available in some areas meant that certain assumptions had to be made about matters which could influence capital costs. Also certain cost items had to be specifically excluded from the estimates. These assumptions and exclusions are listed in Table 4.4.

After the studies were completed, Inco indicated that it had examined several options in a pre-feasibility study which described a further option not included in the evaluations requested by the Task Force. However, this option was similar to one of those developed for the Task Force, i.e. roast/reduction smelting, except that it involved the use of some of the existing equipment at the IORP. Closure of the IORP for pyrrhotite processing was proposed, with the fluid bed roasters and the acid plants to be used for treatment of the nickel/copper concentrate and for containment of the SO_2 emissions. The fluid bed roaster calcine would be transferred to the existing smelter where electric smelting furnaces (operated in the reduction mode) would be installed for the production of a nickel/copper matte. Since this scheme left the copper circuit unchanged, emissions would be reduced to 894 tonnes per day, 92 tonnes of which would be emitted from the IORP stack (Program IV).

During the course of developing this concept, some of the options developed in the Task Force studies were also examined by Inco and costs were subsequently derived. These costs differed from those derived in the Task Force's assessments and, for similar schemes, were almost $300 million (over 60%) higher. The major differences arise from the basic assumptions made by the consultants and the factors which were knowingly excluded from their considerations (Appendix 4.2). It is believed that these exclusions account for the difference between the costings to well within the degree of accuracy of minus 10% to plus 50% estimated to apply to the figures developed in the Task Force studies.

The primary focus with respect to operating costs was the difference between costs incurred in the existing production process and the costs of operating a process modified by one of the abatement programs. The Task Force derived estimates of the total operating costs from the elements included in each abatement program. Subsequent analysis, based on data supplied by Inco and other sources, established approximate total operating costs for those parts of the existing process which would be replaced by the abatement program element. The difference between the two sets of costs equals the incremental operating cost of each abatement program, with regard to energy, material and labour costs only. By-product sales revenues are not included in this evaluation.

4.2 Description of Abatement Programs

The selection of abatement technology options described here was based on the conclusions drawn from a detailed review of the candidate technologies.

Four major process modifications were first selected, each of which could be accompanied by weak gas treatment techniques. In addition, a weak gas treatment process installed at the IORP was chosen as an option virtually independent of any other process or containment technology which could be applied.

The major process options chosen involved:

- modifications to the copper smelting circuit and fixing the SO_2 in the nickel matte processing roaster off-gas (CCM);
- roast/reduction smelting, as under development by Inco at Thompson (RRS);
- Outokumpu flash furnace smelting technology applied to the nickel circuit (OFF);
- Inco's alternative using the IORP for nickel roast/reduction smelting of nickel/copper concentrate (IRRA);
- absorption of the IORP off-gases in non-regenerative weak gas treatment (IORP).

The use of regenerative or non-regenerative weak gas treatment systems were then considered as additional treatments for use in combination with the first four major options. The weak gas systems are identified by letters A, C and E referring to regenerative systems and B, D and F referring to non-regenerative systems. Their use should be preceded by the large process modifications, since the use of these absorption systems on the dilute streams currently existing would require massive installations at excessive cost, pose major waste disposal problems and offer no advantage over modernization by the process technologies. Schematic representations of these selected programs are shown in Figures 4.1 to 4.8, while cost data are listed in Tables 4.2 and 4.3. Appendix 4.1 lists the combinations of technologies identified as technically feasible for examination.

The choice of abatement programs described in this Chapter was based on the conclusions drawn from a detailed review of the candidate abatement technologies. The four principal conclusions were that:

- Reduction in SO_2 emissions below the level to be achieved by the modified pyrrhotite rejection process could be accomplished most quickly by fixation of the SO_2 in the nickel matte processing roaster off-gases and by modifications in the copper smelting circuit.

- The most significant single reduction would result from containment and fixation of the copper circuit Pierce-Smith converter off-gas, flash furnace off-gas that currently by-passes the liquid SO_2 plant and the SO_2 liquefaction plant tail gas. However, even with all practicable changes to the copper circuit and containment of the nickel matte processing roaster off-gas, SO_2 emissions from the smelter would still be of the order of 1,150 tonnes per day.

- To effect significantly greater reductions in emissions, it would be essential to carry out major modifications to the nickel smelting circuit. These modifications would entail replacing the existing multi-hearth roasting/reverberatory furnace smelting system with either a fluid bed roasting/electric furnace smelting system or with a flash smelting system. Either of these changes, together with the changes listed in the preceding conclusion, would reduce SO_2 emissions below 300 tonnes/day. Moreover, this level would be attainable without treatment of weak gas streams.

- Emission levels below 50 tonnes per day could be achieved by adding treatment of weak gas streams to the combined copper and nickel circuit modifications. Such treatment could be by regenerative processes yielding a strong SO_2 stream that could be fed to an acid plant, or by non-regenerative processes that result in by-products.

Taking account of these conclusions, three basic illustrative abatement programs were developed; one involving changes to the copper circuit and two involving changes to both the copper and nickel circuits.

The fourth program, which could form a final step in reducing overall Inco SO_2 emissions, involves weak gas treatment at the IORP. In concept, this program would further reduce emissions by containing SO_2 from the top-blown rotary converter off-gases. It would also collect emissions from the IORP roaster off-gases and the acid plant tail gas, reducing the IORP emissions to 19 tonnes/day. The IORP is at present subject to a separate emissions limit of 227 tonnes (250 tons) per day under the Control Order issued in 1973.

In addition to these four programs, the possibility of modifying only the nickel circuit is presented. This program, developed by Inco as an alternative which would utilize some of the existing IORP equipment, could be instituted at a much lower capital cost than the full options covering both circuits. However, it would take longer to be installed than the copper circuit modifications and, by itself, would not achieve the same degree of reduction of emissions as the full programs. In addition, the manufacture of a special type of nickel oxide, presently produced at the IORP, would be discontinued unless alternative methods of production using normal quality nickel were found.

Although the emphasis in this report has been on SO_2 emissions, preliminary estimates have also been made of possible reductions in the emissions of particulates arising from the smelter modifications suggested in the abatement programs. There are no firm data concerning these emissions from the newly suggested smelting and converting operations, nor are the figures for removal efficiency of particulate matter by the acid plants, the weak gas treatment plants and the upgraded or new electrostatic precipitators yet available. The efficiencies will, regardless of the equipment designs, be dependent on the as yet unknown particle size distribution and quantities of materials with which the various particulate collection devices are presented.

It is estimated that overall particulate emissions can be reduced to about one quarter of their current levels, i.e. a 75% reduction.

Any attempt to further refine the above estimate is considered to be unjustifiable in view of the known inaccuracies, the paucity of existing particulate emission data and the absence of design details for the programs.

In order to achieve a higher degree of particulate emission reduction (about 90% reduction), careful attention would need to be given to some or all of the following aspects:

- installation, where new electrostatic precipitators are needed, of high efficiency equipment capable of being effectively operated at varying gas flow rates;
- upgrading of existing precipitators with respect to efficiency and flexibility of operations;
- effective hooding of the converters and other sources of particulate emissions so as to achieve a high degree of particulate capture;
- well-designed ductwork and dampering systems to permit easy and good maintenance and freedom from points of air ingress (which might affect indraught at the hoods);
- a high level of maintenance to the precipitators, hoods and ductwork.

Only when final designs and reliable qualitative and quantitative particulate emissions data from each specific source are available, will a detailed evaluation be feasible for reductions in these emissions.

4.2.1 Abatement Program I: Copper Circuit Modifications

4.2.1.1 Modifications to Process Operations

Programs I, IA and IB are shown schematically in Figures 4.1 and 4.2. The primary feature of these programs is the installation of tight-fitting primary and secondary hoods on the copper converters. The purpose of the primary hoods is to collect the converter off-gas at an SO_2 concentration adequate for acid-making (4% or more). A ducting system would take the off-gases from the hoods to a new acid plant at the smelter. The secondary hoods collect an off-gas stream weak in SO_2 and play an important role in maintaining an acceptable workplace environment. The gases collected by the secondary hoods would be directed either to the 381 m stack or to a weak gas treatment plant, depending on whether or not the A or B program is implemented.

In all three programs, the portion of the high strength copper flash furnace off-gas which is not captured by the existing liquid SO_2 plant would be treated in the new acid plant, along with the tail gas from the liquid SO_2 plant.

The programs also include one modification related to the nickel circuit. The relatively small off-gas stream from the fluid bed roasters in the matte processing system would also be directed to this acid plant.

In programs IA and IB, two weak gas treatment plants are proposed to treat the tail gas from the new acid plant; the other plant would treat only the secondary hood gas.

Although the containment and fixation of off-gases from Pierce-Smith converters are practised efficiently elsewhere in the copper industry, it is recognized that the presence of nickel in the copper smelting circuit at Copper Cliff complicates such containment. Nevertheless, the Task Force believes that the installation of a tight-fitting converter hood system to the copper converters may represent the most positive short-term approach to reducing SO_2 emissions from the smelter. Other potential benefits from this approach include substantial reductions in fugitive SO_2 and particulate emissions from the smelter.

4.2.1.2 Impact on Sulphur Dioxide and Other Emissions

Program I would reduce SO_2 emissions from a level of 1,766 tonnes/day to 1,146 tonnes/day or 418,300 tonnes/year. The addition of weak gas treatment with Program IA or IB would reduce emissions by a further 125 tonnes/day to 1,021 tonnes/day or 372,670 tonnes/year.

These programs are expected to cause a reduction in particulate emissions as a result of the more efficient removal of particulate from gases which now go to the 381 m stack but which would in future be directed to an acid plant. (Operation of an acid plant requires that incoming gases pass through gas cleaning systems which remove virtually all particulate matter.)

The secondary hoods on the copper converters may improve the workplace environment, although the extent of the improvement cannot be predicted on the basis of the Task Force's conceptual engineering studies.

None of the programs will have any impact on emissions of nitrogen oxides since these are related to the reverberatory furnaces in the nickel circuit.

4.2.1.3 Capital and Operating Costs

The estimated capital cost for Program I is $75 million, for Program IA, $150.7 million, and for program IB, $143.5 million, depending on whether a regenerative or non-regenerative weak gas treatment system is used. Costs are given in Tables 4.2 and 4.3.

4.2.1.4 By-Products of Emission Reduction

Two by-products would be produced from the treatment of strong and weak gas streams in Programs I, IA and IB. These are sulphuric acid and gypsum. Quantities are as follows:

Abatement Program	Sulphuric Acid (96%)	Gypsum
I	951 tonnes/day	-
IA	1,141 tonnes/day	-
IB	951 tonnes/day	335 tonnes/day

These amounts of sulphuric acid are in addition to acid produced at the existing IORP plant.

4.2.1.5 Development, Engineering and Construction Time

Programs I, IA and IB all make use of existing technology and would not require any development period. The time required for engineering and construction (either program) is estimated to be two years. This estimate assumes that the tight-fitting hoods, presently available in the copper smelting industry, can be readily installed on the existing copper converters at the Copper Cliff smelter.

4.2.2 Abatement Program II: Inco Roast/Reduction Smelting Plus Programs I, IA and IB

4.2.2.1 Modifications to Process Operations

The elements of Programs II, IIC and IID are shown schematically in Figures 4.3 and 4.4. Program II includes all elements of Program I and Programs IIC and IID incorporate Programs IA and IB respectively.

The basis of Program II (aside from the Program I elements) is the replacement of the existing hearth roaster/reverberatory furnace system in the nickel smelting circuit with the Inco roast/reduction smelting process. This is one of the three technologies considered for the nickel circuit. The roast/reduction smelting process and the process operated by Inco at Thompson, Manitoba both use a combination of fluid bed roasters and electric furnaces. The third technology is flash smelting, which is included in Program III.

The roast/reduction smelting process is currently under development by Inco. Extensive testing of the process has been carried out at the Thompson smelter. The primary advantage of roast/reduction smelting as compared to conventional fluid bed roasting/electric furnace smelting practised by Inco (Thompson) and by Falconbridge is that it eliminates a greater percentage of sulphur in the smelter feed (80% vs 50%) as strong gases in the roaster, which means there is less sulphur to remove in the electric furnaces and the converters (which produce weak gases that are difficult to collect and treat). The amount of fugitive emissions are also reduced; thus, an improvement in working conditions is also achieved.

Even if the roast/reduction smelting process does not completely fulfill expectations, the fluid bed roasters and electric furnaces will perform at least as effectively as the processes at Thompson and Falconbridge. This process still represents a substantial improvement over the existing one if fluid bed roaster off-gases are treated in an acid plant.

Four fluid bed roasters would replace the multi-hearth roasters in the existing smelter to produce a calcine from the nickel/copper concentrate. Off-gas from the roasters would be ducted to an acid plant (separate from the Program I acid plant). Waste heat boilers would be installed with the fluid bed roasters to generate process steam which, in the existing process, is produced by the reverberatory furnace system.

Off-gases from the two electric furnaces and acid plant tail gases would be directed to the smelter stack in Program II and to a weak gas treatment plant in Programs IIC and IID. In all programs, the nickel converters would be equipped with tight-fitting hoods, although the off-gas would not go to an acid plant as in the case of the copper converters. The gas would be emitted to the atmosphere via the smelter stack in Program II and would be sent to weak gas treatment in Programs IIC and IID. Thus, in Program II, the main function of the hoods would be to improve the working area environment.

4.2.2.2 Impact on Sulphur Dioxide and Other Emissions

Program II reduces SO_2 emissions from 1,766 tonnes/day to 243 tonnes/day or 88,700 tonnes/year and Program IIC and IID achieve a level of 24 tonnes/day or 8,760 tonnes/year. The effect of roast/reduction smelting alone is to reduce emissions by 913 tonnes/day to a level of 853 tonnes/day.

All three programs should reduce emissions of particulate matter more than Programs I, IA or IB as a result of greater quantities of gas passing through gas cleaning systems prior to acid manufacture.

Since the reverberatory furnaces are the main source of nitrogen oxides (NO_x) in the existing smelter, their replacement with electric furnaces (which do not generate NO_x) will reduce considerably the already low level of NO_x emissions.

Programs II, IIC and IID may improve the working area environment as a result of the hoods installed on the copper and nickel converters.

4.2.2.3 Capital and Operating Costs

The estimated capital cost for Program II (Options 1 and 2) is $339 million, and for Programs IIC and IID, $483 million or $465 million, depending on whether a regenerative or non-regenerative weak gas treatment system is used. A cost breakdown is given in Tables 4.2 and 4.3.

4.2.2.4 By-Products of Emission Reduction

Quantities of by-product sulphuric acid and gypsum produced by Programs II, IIC and IID would be as follows:

Abatement Program	Sulphuric Acid	Gypsum
II	2,420 tonnes/day	-
IIC	2,756 tonnes/day	-
IID	2,420 tonnes/day	589 tonnes/day

These amounts of sulphuric acid are additional to the acid presently being produced at the IORP acid plant.

4.2.2.5 Development, Engineering and Construction Time

The Inco roast/reduction smelting process has had considerable testing, but it is estimated that an additional year of development time would be required before the start of detailed engineering and construction. Although engineering and construction of the copper circuit modifications could be completed within two years, as in Program I, the time required to develop, engineer and construct the roast/reduction smelting process would extend the implementation time for Programs II, IIC and IID to four years development (one year engineering and three years construction for Programs II, IIC and IID).

In practice, in order to keep interferences with normal production and maintenance operations to a minimum, it would be necessary to extend the time frame for any construction taking place in existing work areas. As a result, for Program II, it is estimated that as much as an extra year overall would be required should the level of interference be unacceptable.

4.2.3 Abatement Program III: Outokumpu Flash Smelting Plus Programs I, IA and IB

4.2.3.1 Modifications to Process Operations

The elements of Programs III, IIIE and IIIF are presented schematically in Figures 4.5 and 4.6. Program III includes all elements of Program I and Programs IIIE and IIIF incorporate Programs IA and IB respectively.

Aside from the Program I elements, Programs III, IIIA and IIIB are based upon the implementation of the other principal option for nickel smelting, that of flash smelting. In theory, either Inco or Outokumpu technology can be applied. It is known that, in the past, Inco has devoted considerable effort to studying and evaluating the application of its copper flash smelting process to the treatment of its nickel/copper concentrates. More recently, however, the Company's efforts have been directed at the roast/reduction smelting process, in view of its potential advantages.

Outokumpu technology is a realistic alternative to a fluid bed roasting/electric furnace smelting combination, and it is a proven process with installations operating in Finland, Botswana, Australia and, recently, in the USSR. The abatement program is based upon data relating to the conventional hot air Outokumpu furnace, although it is accepted that the more modern oxygen-enriched air furnace is the preferred technology; however, insufficient data were available on this latter system to allow a proper evaluation at the time of the study.

Nickel/copper concentrate would be dried in two fluid bed dryers and then smelted in an Outokumpu flash furnace. Flash furnace off-gas would be ducted to an acid plant (separate from the Program I acid plant).

In Program III, the off-gases collected by tight-fitting hoods on the nickel converters and the acid plant (plants A and C) tail gases would be sent to the smelter stack; in Programs IIIE and IIIF both tail gas streams would go to weak gas treatment plants.

Flash smelting requires an additional system for recovering metals from the flash furnace slag (usually referred to as slag cleaning). Program III includes three slag cleaning electric furnaces capable of handling slag from the flash furnace plus that from the copper and the nickel Pierce-Smith Converters.

4.2.3.2 Impact on Sulphur Dioxide and Other Emissions

The Outokumpu flash furnace technology alone (Option 3) would result in an SO_2 emission reduction of 838 tonnes/day, reducing total smelter emissions to 928 tonnes/day.

Program III in total (Options 1 and 3) would reduce SO_2 emissions to 297 tonnes/day or 108,400 tonnes/year, while Programs IIIE and IIIF would further reduce the level of emissions to 30 tonnes/day or 10,950 tonnes/year.

Reductions in particulate and nitrogen oxides would be similar to Programs II, IIC and IID.

4.2.3.3 Capital and Operating Costs

The estimated capital cost for Program III (Options 1 and 3) is $346 million, and for Programs IIIE and IIIF, $491 million (regenerative weak gas treatment) or $471 million (non-regenerative weak gas treatment). A cost breakdown is given in Tables 4.2 and 4.3.

4.2.3.4 By-Products of Emission Reduction

Programs III, IIIE and IIIF produce slightly smaller quantities of sulphuric acid than Programs II, IIC and IID, but the amounts of gypsum produced in Program IIIE are larger than in Program IIC as a result of having more weak gases to treat. Quantities of the two by-products are as follows:

Abatement Program	Sulphuric Acid	Gypsum
III	2,331 tonnes/day	-
IIIE	2,740 tonnes/day	-
IIIF	2,331 tonnes/day	719 tonnes/day

These amounts of sulphuric acid are additional to the acid presently being produced at the IORP acid plant.

4.2.3.5 Development, Engineering and Construction Time

The Outokumpu flash smelting system is considered to be a proven, "off-the-shelf", technology and therefore, no allowance has been made for any development time. Engineering and construction time is estimated to be three years for either of the programs. The copper circuit modifications (the Program I elements) could be completed within two years. Similar to previously described programs, a further delay of one year may be required if production interruptions cannot be accepted.

4.2.4 Abatement Program IV: Inco's Roast/Reduction Smelting Alternative

4.2.4.1 Modifications to Process Operations

As stated in the description of Programs IIC and IID, Inco has devoted considerable effort to development of the roast/reduction smelting process as a replacement for the current multi-hearth roaster/reverberatory furnace nickel smelting system. The Company has commissioned several engineering studies to investigate how this new process could best be installed at Copper Cliff and what costs would be involved. Through presentations made by Inco and through discussions with Company officials, a picture of Inco's preferred roast/reduction smelting alternative has been constructed.

The most significant difference between Program IV and Programs IIC and IID is that new fluid bed roasters would not be constructed in the existing smelter to replace the multi-hearth roasters. Instead, existing fluid bed roasters in the Iron Ore Recovery Plant (IORP) would be used for roasting the nickel/copper concentrate. The IORP is located some 4 km from the Copper Cliff mill and smelter. The concentrate would have to be transported from the mill to the IORP, then the roaster calcine would have to be transported back to the smelter where the electric furnaces would be installed. Thus, the cost of materials handling facilities would offset, to some extent, the savings from using the existing roasters.

Other important points with respect to this program are:

- the existing IORP operations would be discontinued and production of nickel oxide and iron oxide from pyrrhotite concentrate would cease, thereby eliminating SO_2 emissions from this source;

- roaster off-gases would be treated in the existing IORP acid plants; the sulphuric acid presently produced at the IORP would be replaced by this new source of acid such that these strong gases from the nickel circuit would not generate acid in addition to that presently produced;
- no provision is made for tight-fitting hoods to allow the making of acid from copper or nickel converter off-gases;
- gases from the copper flash furnace which by-pass the liquid SO_2 plant, the liquid SO_2 plant tail gas and gases from the nickel circuit matte processing area would not be captured for acid manufacture;
- nickel in the pyrrhotite would not be recovered; hence, additional ore would need to be mined to replace the lost metal values.

Further examination of this program in conjunction with other programs, in particular copper circuit modifications, has not been attempted in view of time constraints. A schematic of this program is presented in Figure 4.7.

4.2.4.2 Impact on Sulphur Dioxide and Other Emissions

The Inco engineering studies assume nominal design with production capacity of 300 million lb of nickel per year, but a nickel/copper concentrate feed rate of 2,270 tonnes/day, which is only slightly higher than the feed rate assumed in the Task Force studies. Program IV would reduce total SO_2 emissions from the smelter to 802 tonnes/day and emissions from the IORP to 92 tonnes/day.

Program IV would result in a reduction in particulate emissions and a considerable reduction in emissions of nitrogen oxides by replacing the reverberatory furnaces with electric furnaces.

It is also expected that an improvement in the converter working area environment would be achieved due to the matte being sulphur deficient. Fugitive emissions during matte transport and converter blowing would be greatly reduced. The primary function of the converter chemistry would then revolve around the removal of excess iron rather than around the removal of sulphur as is presently the case.

4.2.4.3 Capital and Operating Costs

Inco estimates that the total capital cost of this program would be $430 million (January 1982 Canadian dollars), which is considerably higher than estimates available to the Task Force of the most nearly comparable abatement option, i.e., Option 2 at $247 million.

Inco's cost estimates do not include escalation and interest charges, nor the cost of any lost production. They do include a contingency allowance, engineering costs, indirect costs, taxes, freight, insurance and capital spares. Of major importance are the costs of construction delays, due to the need to dovetail construction with production needs, and the costs for the demolition of existing facilities.

Major differences have been examined in efforts to reconcile the two cost levels. The differences are indicated in Appendix 4.2 for installations at the existing smelter and, within the accuracy of estimation, no significant unexplainable differences have been found.

Operating costs for the new process were not disclosed, although it was indicated that production costs would decrease to some extent.

4.2.4.4 By-Products of Emission Reduction

The only new emission by-product would be sulphuric acid produced in the existing IORP acid plants. The annual production of acid would be approximately 1,487 tonnes/day at a roaster concentrate feed rate of 2,270 tonnes/day. For comparative purposes, sulphuric acid production at these plants in recent years has been in excess of 2,000 tonnes per day. An existing containment of SO_2 at a rate of 229 tonnes/day (as liquid SO_2 product) would continue.

4.2.4.5 Development, Engineering and Construction Time

Inco estimates that a period of six to seven years would be required for the installation of this process.

4.2.5 Abatement Program V: IORP Weak Gas Treatment

4.2.5.1 Modifications to Process Operations

The current process employed at the IORP has been described in Chapter 3. At present, the only sources of strong SO_2 off-gas are the fluid bed roasters. The gas is treated in sulphuric acid plants. The only atmospheric emissions of SO_2 are the acid plant tail gas and roaster off-gas which by-pass the plants. However, the SO_2 emissions from one component of the nickel circuit, the top-blown rotary converters (TBRCs) in the nearby nickel refinery, are discharged through the IORP stack. Consequently, this source of weak gas is included with the IORP abatement program, rather than with Programs II and III dealing with the nickel circuit.

Program V consists of a single non-regenerative weak gas treatment plant which handles the tail gas and by-pass gas from the existing acid plants and the TBRC off-gas. A schematic of the program is given in Figure 4.8.

4.2.5.2 Impact on Sulphur Dioxide and Other Emissions

Program V reduces IORP stack SO_2 emissions from a level of 192 tonnes/day to approximately 19 tonnes/day, or on an annual basis, from 70,100 tonnes to 7,010 tonnes.

The program would reduce particulate emissions from the IORP stack but would have no effect on the working area environment.

4.2.5.3 Capital and Operating Costs

The estimated capital cost for the single non-regenerative weak gas treatment plant in Program V is $41.0 million.

4.2.5.4 By-Products of Emission Reduction

Since this program incorporates only non-regenerative weak gas treatment, gypsum is the only by-product. It would be produced at a rate of 464 tonnes/day and would have to be disposed of as waste if no market emerged.

4.2.5.5 Development, Engineering and Construction Time

The length of time to engineer and construct the weak gas treatment plant would be approximately one year.

4.3 Conclusions

Of the abatement technologies outlined in Chapter 3, four process modifications (options) to produce strong SO_2, which is collected in acid plants, have been selected for detailed examination and these four modifications combined with weak gas treatment offer a total of ten possible programs, excluding the IORP (weak-gas treatment) option.

Other programs can be created by combining the above options in different ways (Appendix 4.1).

The selection of a particular program, depending on the combinations involved, may preclude the addition of other technologies at a later date, or modifications to the program if circumstances change. It is important, therefore, to examine the flexibility, or lack thereof, associated with these basic technologies.

The type of weak gas treatment must be determined at the outset of a program, due to the different requirements for regenerative and non-regenerative treatment systems.

The five independent options considered in this report (four of which are process changes - CCM, OFF, RRS and IRR, and three of which are also technological improvements - CCM, OFF and RRS) are:

- modifications to the copper circuit (CCM);
- roast/reduction smelting in the existing smelter (RRS);
- Outokumpu flash furnace smelting (OFF);
- roast/reduction smelting in the Iron Ore Recovery Plant (IRRA);
- non-regenerative weak gas treatment of the Iron Ore Recovery Plant emissions (IORP).

Of these, the first three are combined with weak gas treatment in regenerative and non-regenerative modifications to produce six more options.

The copper circuit modifications, reducing total smelter SO_2 emissions to 1,146 tonnes/day, offer the most rapid reductions but would be less effective than the nickel flash furnace or roast/reduction smelting modifications which could reduce emissions to below 1,000 tonnes/day.

These latter modifications can be combined with the copper circuit modifications to reduce emissions to under 300 tonnes/day, which, with the addition of weak gas treatment, result in emissions of about 30 tonnes/day.

The IORP roast/reduction smelting process (IRRA) can be installed at a lower capital cost than if roast/reduction smelting were installed in the smelter, but it results in the need to discard pyrrhotite, a matter of relatively small concern if iron ore demand is low, but which may, in the future, have more serious consequences. Also, less sulphuric acid would be produced by the IORP acid plants than at present. Considerably less acid would be produced at the overall Inco Sudbury operations compared to the amounts that would be produced from the implementation of other abatement options considered for the nickel circuit, on the assumption that the IORP is operated in its normal mode.

A further advantage is believed to be a reduction in operating costs when compared with any other process, and even a small reduction from the existing process; however, the emission reduction achieved is limited to 1,064 tonnes/day, of which 100 tonnes is from emission reductions at the IORP, unless other modifications, particularly changes to the copper circuit, are also imposed. Further examination of this option is warranted.

The IORP program using weak gas scrubbing is an independent option applicable to the IORP in addition to any of the previously described programs except the IRR program.

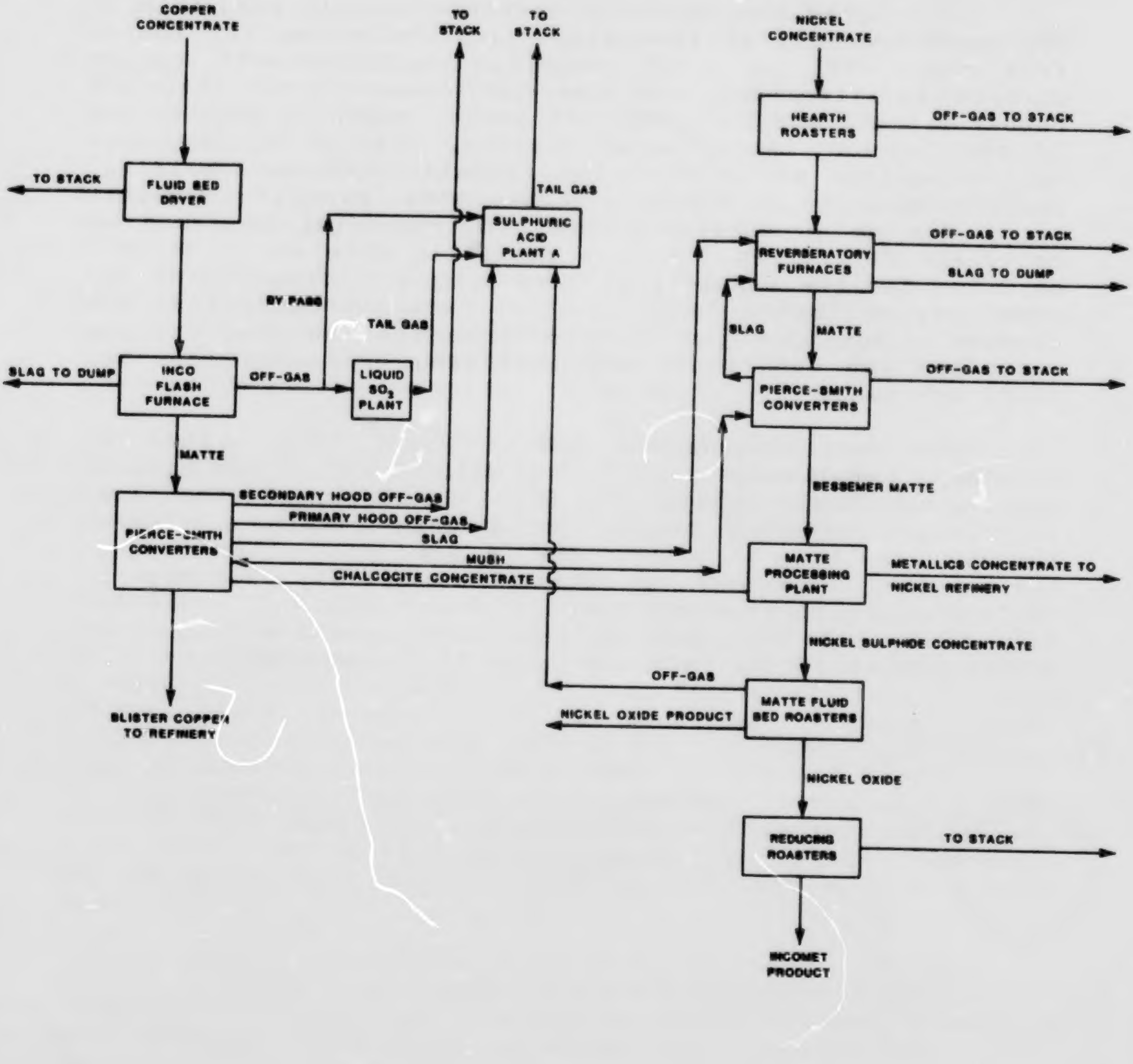
The shortest time which would be required for the installation of each major option is shown in Table 4.2. Assuming that design and engineering work begins in 1983, the earliest date by which a program could be completed and operational is probably 1986. This would be by the installation of an Outokumpu flash furnace or by modifications to the copper circuit.

The program achieving the greatest overall reduction in SO_2 emissions (1,915 tonnes per day including 173 tonnes from the IORP) is roast/reduction smelting with copper circuit modifications and weak gas treatment of both the copper circuit and the IORP. It would, however, require one of the longest installation periods, similar to the Inco option using the IORP for roast/reduction smelting. Completion would be unlikely before 1988, even if no delays arose due to production needs, environmental hearings or materials deliveries. A more realistic date would be 1990 or later for the complete program with a further one or two year period before the initial startup problems are cleared. But of major importance is the low level of SO_2 emissions (43 tonnes per day including 19 tonnes from the IORP) achieved.

The Inco alternative (IRRA) would have a similar extended installation period, but would be less troublesome at the initial startup. One advantage of the Inco alternative is that the existing acid plants are used, thereby resulting in a decrease in acid production through the roasting of nickel concentrate. A similar reduction of SO_2 emissions can be achieved at lower cost using the RRS with IORP, but this program would increase the amount of acid produced if the IORP continues to be operated.

FIGURE 4.1

SCHEMATIC OF INCO ABATEMENT PROGRAM I


COPPER CONCENTRATE
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TO STACK
NICKEL CONCENTRATE
HEARTH ROASTERS
OFF-GAS TO STACK
TO STACK
FLUID BED DRYER
TAIL GAS
SULPHURIC ACID PLANT A
REVERBERATORY FURNACES
OFF-GAS TO STACK
SLAG TO DUMP
BY PASS
TAIL GAS
SLAG
MATTE
SLAG TO DUMP
INCO FLASH FURNACE
OFF-GAS
LIQUID SO2 PLANT
PIERCE-SMITH CONVERTERS
OFF-GAS TO STACK
MATTE
BESSEMER MATTE
SECONDARY HOOD OFF-GAS
PRIMARY HOOD OFF-GAS
SLAG
PIERCE-SMITH CONVERTERS
MUSH
CHALCOCITE CONCENTRATE
MATTE PROCESSING PLANT
METALLICS CONCENTRATE TO NICKEL REFINERY
NICKEL SULPHIDE CONCENTRATE
OFF-GAS
NICKEL OXIDE PRODUCT
MATTE FLUID BED ROASTERS
BLISTER COPPER TO REFINERY
NICKEL OXIDE
REDUCING ROASTERS
TO STACK
INCOMET PRODUCT

FIGURE 4.2

SCHEMATIC OF INCO ABATEMENT PROGRAMS I A AND I B

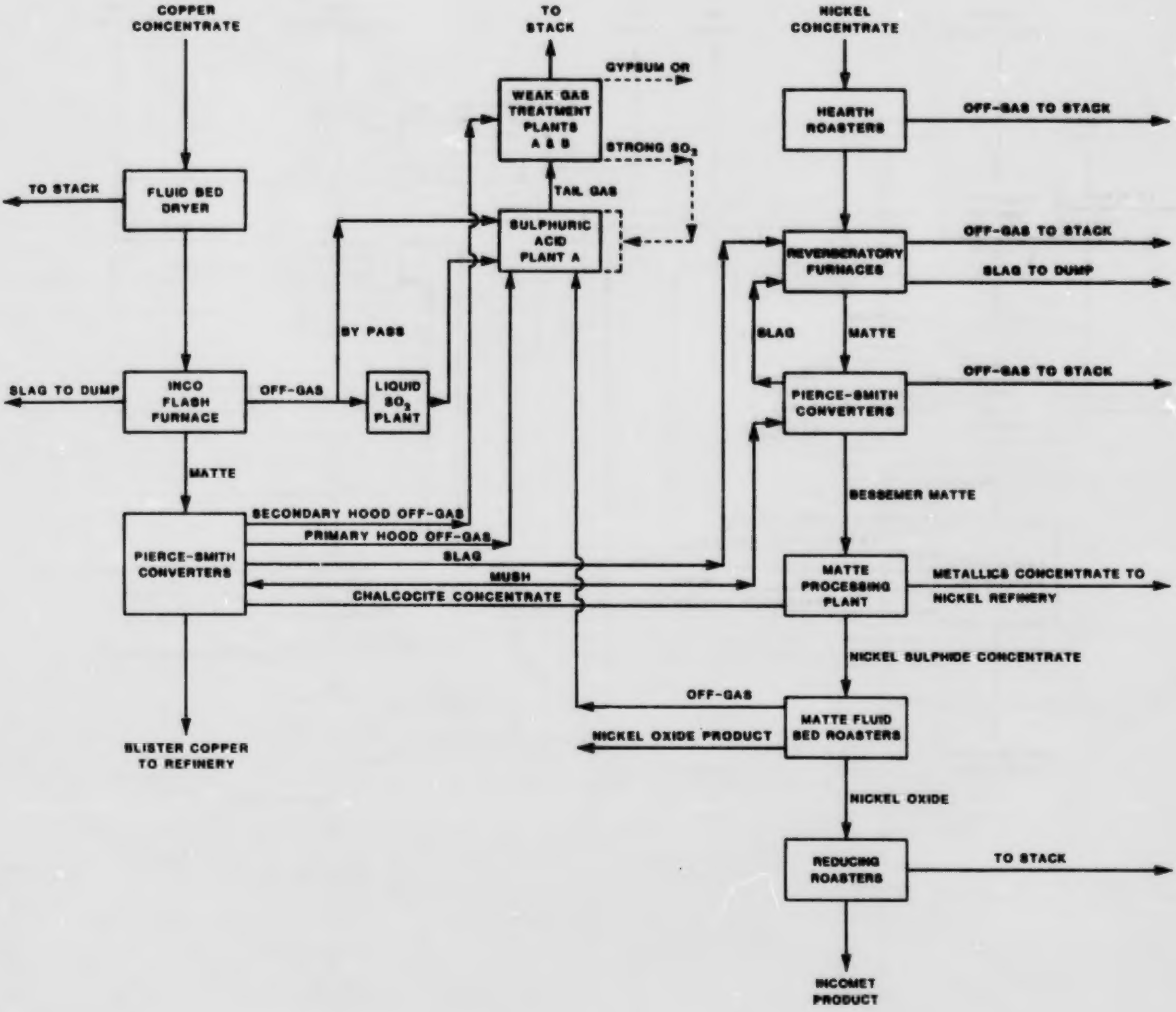

COPPER CONCENTRATE
TO STACK
FLUID BED DRYER
SLAG TO DUMP
INCO FLASH FURNACE
OFF-GAS
BY PASS
LIQUID SO_2 PLANT
MATTE
PIERCE-SMITH CONVERTERS
SECONDARY HOOD OFF-GAS
PRIMARY HOOD OFF-GAS
SLAG
MUSH
CHALCOCITE CONCENTRATE
BLISTER COPPER TO REFINERY
TO STACK
WEAK GAS TREATMENT PLANTS A & B
GYPSUM OR
STRONG SO_2
TAIL GAS
SULPHURIC ACID PLANT A
NICKEL CONCENTRATE
HEARTH ROASTERS
OFF-GAS TO STACK
REVERBERATORY FURNACES
OFF-GAS TO STACK
SLAG TO DUMP
SLAG
MATTE
PIERCE-SMITH CONVERTERS
OFF-GAS TO STACK
BESSEMER MATTE
MATTE PROCESSING PLANT
METALLICS CONCENTRATE TO NICKEL REFINERY
NICKEL SULPHIDE CONCENTRATE
OFF-GAS
MATTE FLUID BED ROASTERS
NICKEL OXIDE PRODUCT
NICKEL OXIDE
REDUCING ROASTERS
TO STACK
INCOMET PRODUCT

FIGURE 4.3

SCHEMATIC OF INCO ABATEMENT PROGRAM II

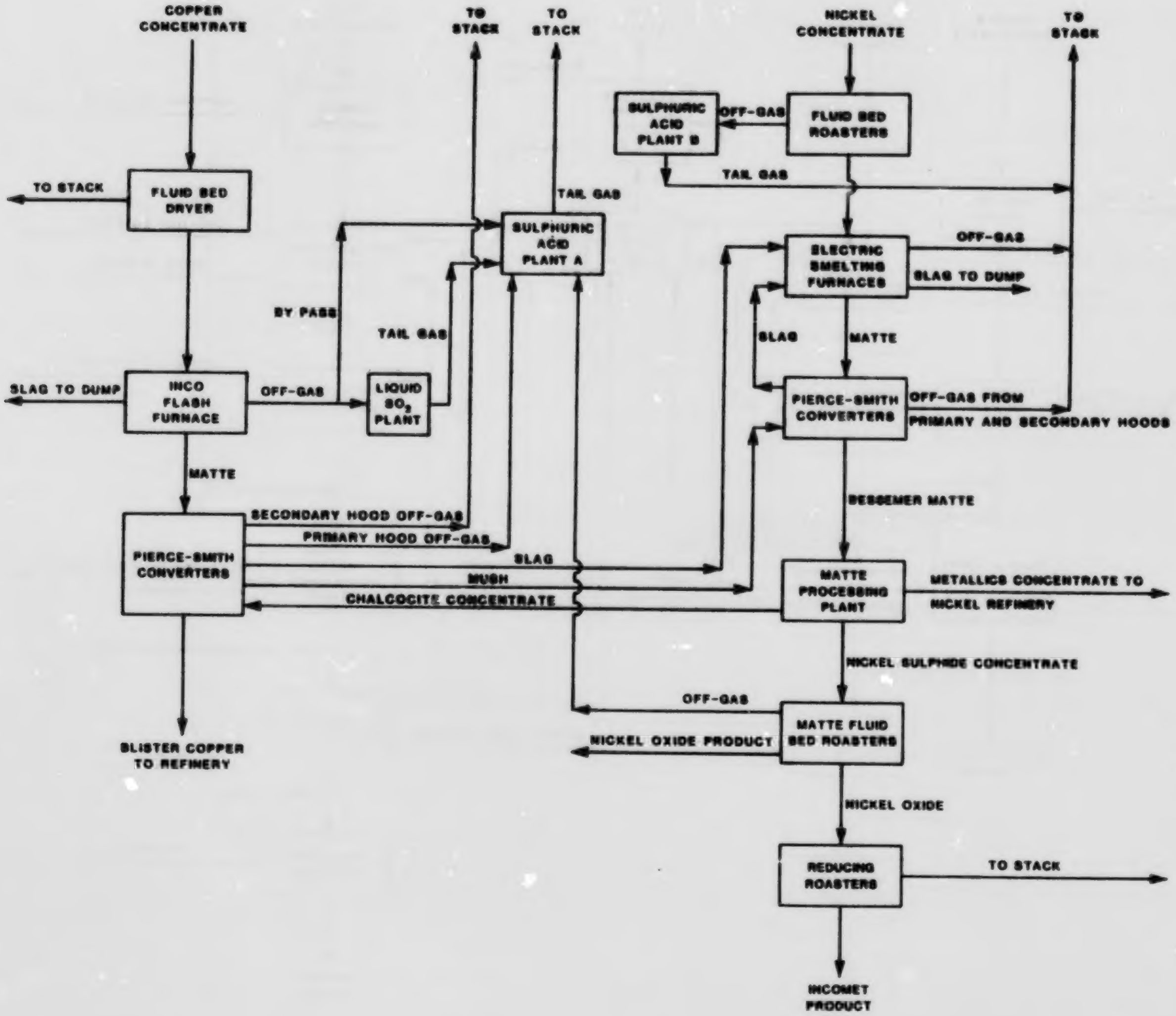

COPPER CONCENTRATE
TO STACK
TO STACK
NICKEL CONCENTRATE
TO STACK
SULPHURIC ACID PLANT B
OFF-GAS
FLUID BED ROASTERS
TAIL GAS
TO STACK
FLUID BED DRYER
TAIL GAS
SULPHURIC ACID PLANT A
ELECTRIC SMELTING FURNACES
OFF-GAS
SLAG TO DUMP
BY PASS
TAIL GAS
SLAG
MATTE
SLAG TO DUMP
INCO FLASH FURNACE
OFF-GAS
LIQUID SO_2 PLANT
PIERCE-SMITH CONVERTERS
OFF-GAS FROM PRIMARY AND SECONDARY HOODS
MATTE
BESSEMER MATTE
SECONDARY HOOD OFF-GAS
PRIMARY HOOD OFF-GAS
PIERCE-SMITH CONVERTERS
SLAG
MUSH
CHALCOCITE CONCENTRATE
MATTE PROCESSING PLANT
METALLICS CONCENTRATE TO NICKEL REFINERY
NICKEL SULPHIDE CONCENTRATE
OFF-GAS
MATTE FLUID BED ROASTERS
NICKEL OXIDE PRODUCT
BLISTER COPPER TO REFINERY
NICKEL OXIDE
REDUCING ROASTERS
TO STACK
INCOMET PRODUCT

FIGURE 4.4

SCHEMATIC OF INCO ABATEMENT PROGRAMS II C AND II D

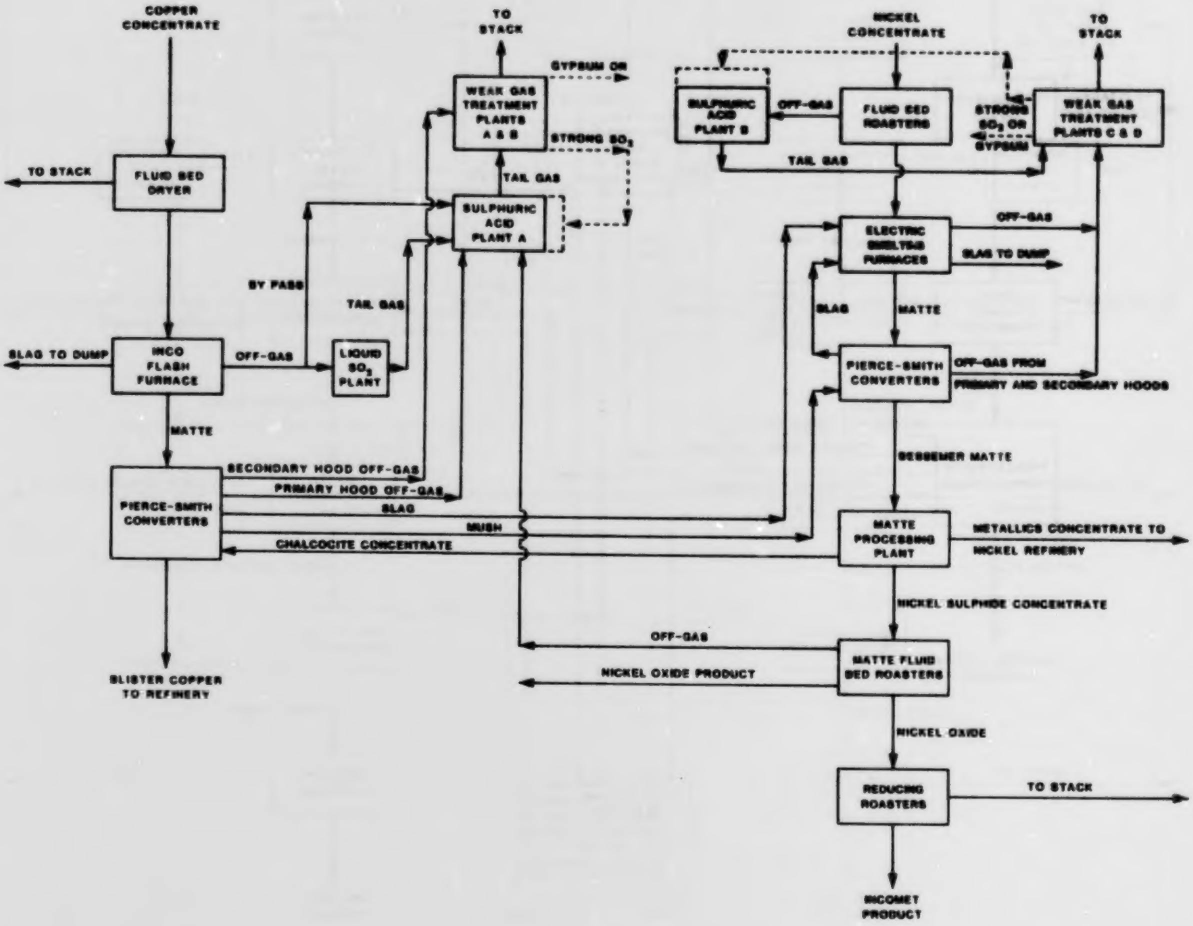

COPPER CONCENTRATE
TO STACK
FLUID BED DRYER
SLAG TO DUMP
INCO FLASH FURNACE
OFF-GAS
BY PASS
LIQUID SO2 PLANT
TAIL GAS
MATTE
PIERCE-SMITH CONVERTERS
SECONDARY HOOD OFF-GAS
PRIMARY HOOD OFF-GAS
SLAG
MUSH
CHALCOCITE CONCENTRATE
BLISTER COPPER TO REFINERY
TO STACK
WEAK GAS TREATMENT PLANTS A & B
GYPSUM OR
STRONG SO2
TAIL GAS
SULPHURIC ACID PLANT A
NICKEL CONCENTRATE
SULPHURIC ACID PLANT B
OFF-GAS
FLUID BED ROASTERS
STRONG SO2 OR GYPSUM
TO STACK
WEAK GAS TREATMENT PLANTS C & D
TAIL GAS
ELECTRIC SMELTING FURNACES
OFF-GAS
SLAG TO DUMP
SLAG
MATTE
PIERCE-SMITH CONVERTERS
OFF-GAS FROM PRIMARY AND SECONDARY HOODS
BESSEMER MATTE
MATTE PROCESSING PLANT
METALLICS CONCENTRATE TO NICKEL REFINERY
NICKEL SULPHIDE CONCENTRATE
OFF-GAS
NICKEL OXIDE PRODUCT
MATTE FLUID BED ROASTERS
NICKEL OXIDE
REDUCING ROASTERS
TO STACK
INCOMET PRODUCT

FIGURE 4.5

SCHEMATIC OF INCO ABATEMENT PROGRAM III

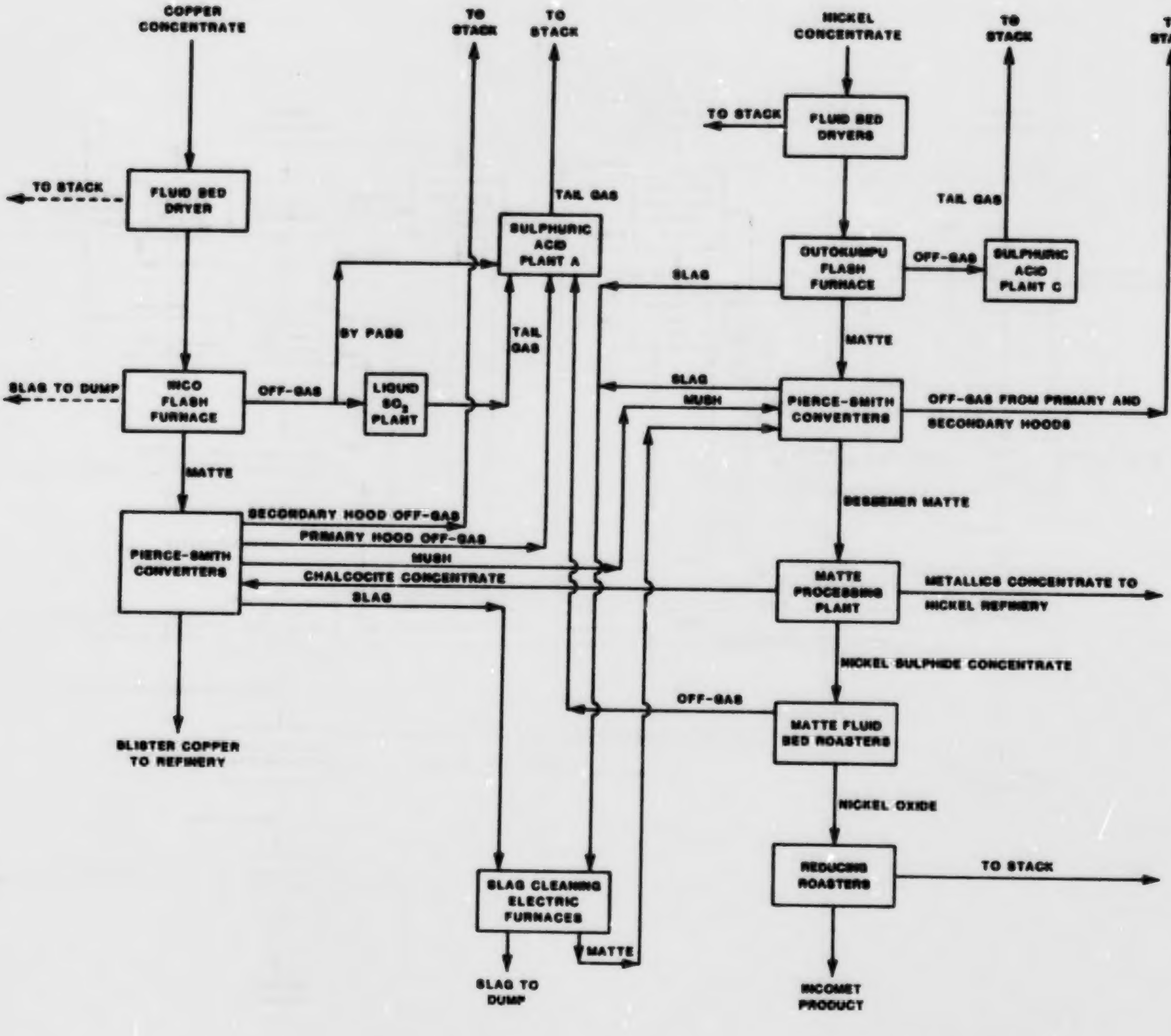

COPPER CONCENTRATE
TO STACK
FLUID BED DRYER
SLAG TO DUMP
INCO FLASH FURNACE
OFF-GAS
BY PASS
LIQUID SO_2 PLANT
TO STACK
TO STACK
TAIL GAS
SULPHURIC ACID PLANT A
TAIL GAS
MATTE
PIERCE-SMITH CONVERTERS
SECONDARY HOOD OFF-GAS
PRIMARY HOOD OFF-GAS
MUSH
CHALCOCITE CONCENTRATE
SLAG
BLISTER COPPER TO REFINERY
SLAG CLEANING ELECTRIC FURNACES
MATTE
SLAG TO DUMP
NICKEL CONCENTRATE
TO STACK
FLUID BED DRYERS
TO STACK
TAIL GAS
OUTOKUMPU FLASH FURNACE
OFF-GAS
SULPHURIC ACID PLANT C
SLAG
MATTE
TO STACK
SLAG
MUSH
PIERCE-SMITH CONVERTERS
OFF-GAS FROM PRIMARY AND SECONDARY HOODS
BESSEMER MATTE
MATTE PROCESSING PLANT
METALLICS CONCENTRATE TO NICKEL REFINERY
NICKEL SULPHIDE CONCENTRATE
OFF-GAS
MATTE FLUID BED ROASTERS
NICKEL OXIDE
REDUCING ROASTERS
TO STACK
INCOMET PRODUCT

FIGURE 4.6

SCHEMATIC OF INCO ABATEMENT PROGRAMS III E AND III F

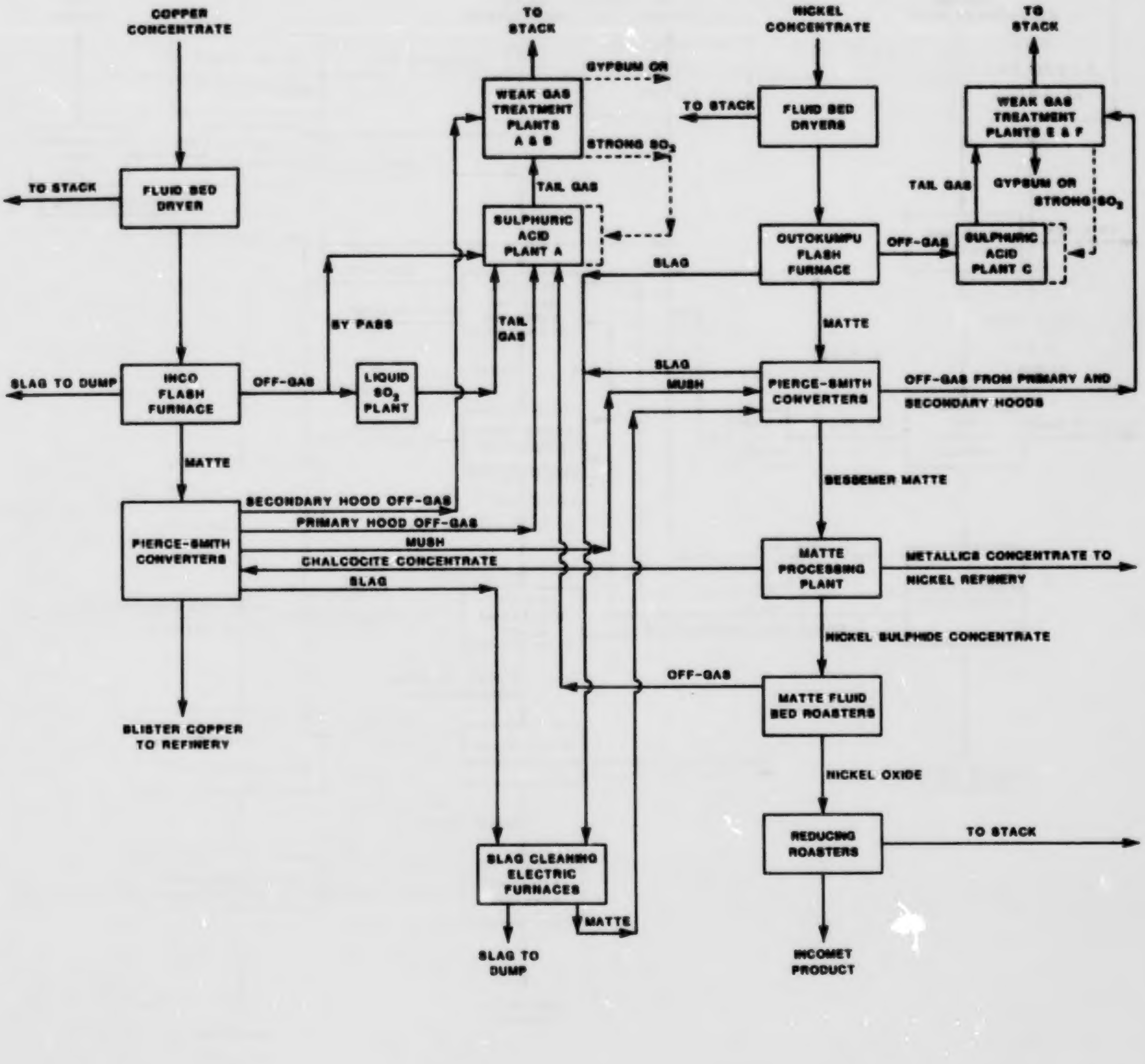

COPPER CONCENTRATE
TO STACK
FLUID BED DRYER
SLAG TO DUMP
INCO FLASH FURNACE
OFF-GAS
LIQUID SO2 PLANT
BY PASS
TAIL GAS
MATTE
PIERCE-SMITH CONVERTERS
SECONDARY HOOD OFF-GAS
PRIMARY HOOD OFF-GAS
MUSH
CHALCOCITE CONCENTRATE
SLAG
BLISTER COPPER TO REFINERY
TO STACK
WEAK GAS TREATMENT PLANTS A & B
GYPSUM OR
STRONG SO2
TAIL GAS
SULPHURIC ACID PLANT A
SLAG CLEANING ELECTRIC FURNACES
SLAG TO DUMP
MATTE
NICKEL CONCENTRATE
TO STACK
FLUID BED DRYERS
OUTOKUMPU FLASH FURNACE
SLAG
OFF-GAS
MATTE
SLAG
MUSH
PIERCE-SMITH CONVERTERS
OFF-GAS FROM PRIMARY AND SECONDARY HOODS
BESSEMER MATTE
MATTE PROCESSING PLANT
METALLICS CONCENTRATE TO NICKEL REFINERY
NICKEL SULPHIDE CONCENTRATE
OFF-GAS
MATTE FLUID BED ROASTERS
NICKEL OXIDE
REDUCING ROASTERS
TO STACK
INCOMET PRODUCT
TO STACK
WEAK GAS TREATMENT PLANTS E & F
TAIL GAS
GYPSUM OR STRONG SO2
SULPHURIC ACID PLANT C

FIGURE 4.7

SCHEMATIC OF INCO ABATEMENT PROGRAM IV

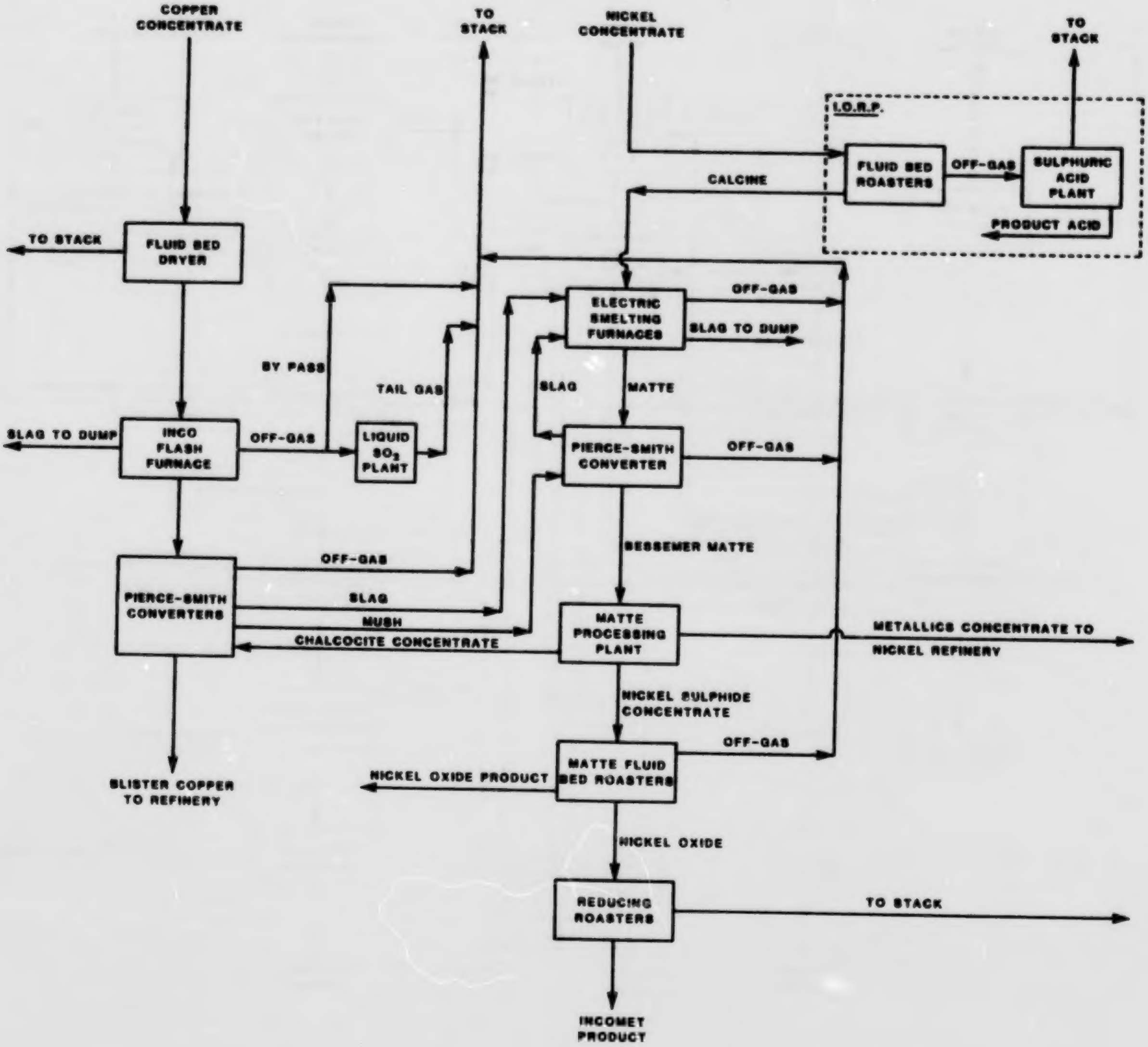

COPPER CONCENTRATE
TO STACK
NICKEL CONCENTRATE
TO STACK
I.O.R.P.
FLUID BED ROASTERS
OFF-GAS
SULPHURIC ACID PLANT
CALCINE
PRODUCT ACID
TO STACK
FLUID BED DRYER
ELECTRIC SMELTING FURNACES
OFF-GAS
SLAG TO DUMP
BY PASS
TAIL GAS
SLAG
MATTE
SLAG TO DUMP
INCO FLASH FURNACE
OFF-GAS
LIQUID SO_2 PLANT
PIERCE-SMITH CONVERTER
OFF-GAS
BESSEMER MATTE
OFF-GAS
PIERCE-SMITH CONVERTERS
SLAG
MUSH
CHALCOCITE CONCENTRATE
MATTE PROCESSING PLANT
METALLICS CONCENTRATE TO NICKEL REFINERY
NICKEL SULPHIDE CONCENTRATE
OFF-GAS
MATTE FLUID BED ROASTERS
NICKEL OXIDE PRODUCT
BLISTER COPPER TO REFINERY
NICKEL OXIDE
REDUCING ROASTERS
TO STACK
INCOMET PRODUCT

FIGURE 4.8

SCHEMATIC OF INCO ABATEMENT PROGRAM V

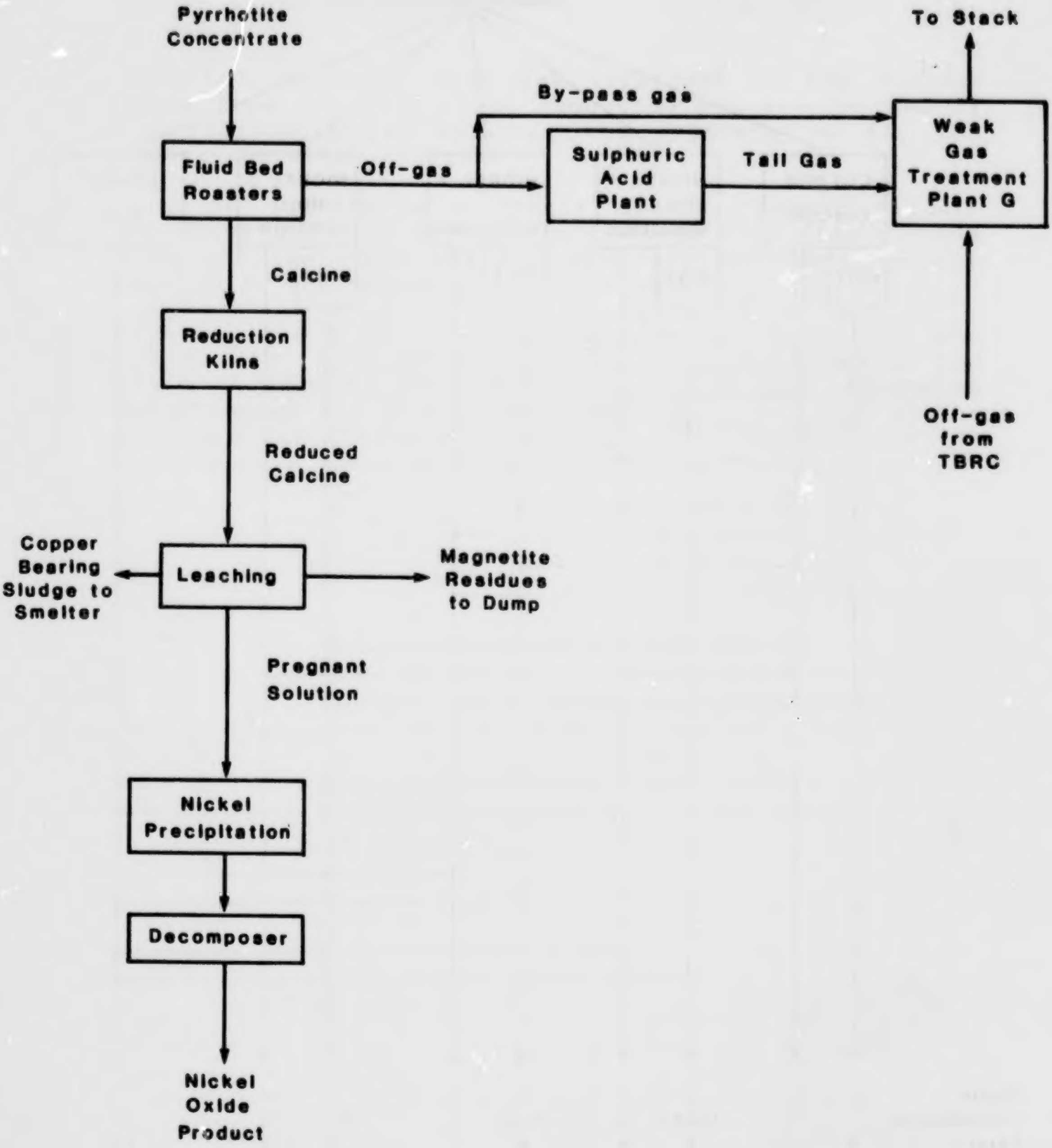
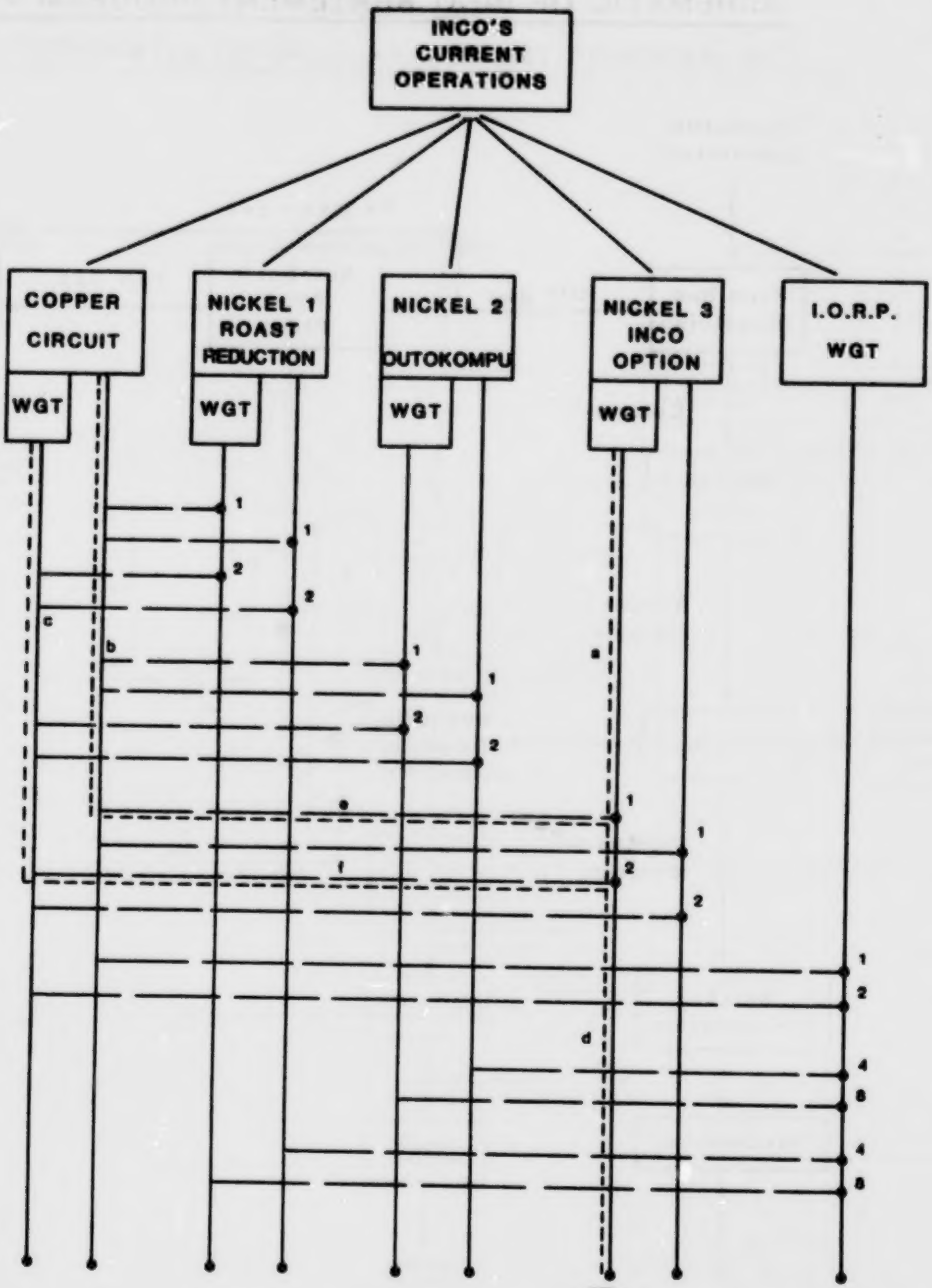

Pyrrhotite Concentrate
Fluid Bed Roasters
Off-gas
By-pass gas
Sulphuric Acid Plant
Tail Gas
Weak Gas Treatment Plant G
To Stack
Off-gas from TBRC
Calcine
Reduction Kilns
Reduced Calcine
Copper Bearing Sludge to Smelter
Leaching
Magnetite Residues to Dump
Pregnant Solution
Nickel Precipitation
Decomposer
Nickel Oxide Product

FIGURE 4.9
SELECTED COMBINATIONS OF ABATEMENT PROGRAMS FOR INCO LIMITED


INCO'S CURRENT OPERATIONS
COPPER CIRCUIT
NICKEL 1 ROAST REDUCTION
NICKEL 2 OUTOKOMPU
NICKEL 3 INCO OPTION
I.O.R.P. WGT
WGT
WGT
WGT
WGT
1
1
2
2
c
b
1
a
1
2
2
e
1
1
f
2
2
1
2
d
4
8
4
8

Single	2	1	2	1	2	1	2	1	1
Combinations	-	-	(2x3)	3	(2x3)	3	(2x3)	3	27
Total	2	1	8	4	8	4	8	4	28

NOTES:

1) Horizontal tie lines indicate selected compatible combinations.
2) Numbers indicate the number of options arising from the combinations.
3) Phasing constraints are not included; hence location of tie lines does not indicate a time sequence.
4) Weak gas treatment (WGT) includes the two options: regenerative and non-regenerative.

FIGURE 4.9 (continued)

1. This example covers eight combinations of abatement programs covering Nickel 3 Inco option and copper circuit. These combinations are identified by the dotted lines which are labelled with the letters a, b, c, and d.

2. Line (a) indicates weak gas treatment of the exhaust gases from the IORP roast reduction process (Nickel 3) and represents two options, the regenerative and the non-regenerative systems.

3. Line (b) indicates a single option, copper circuit modifications with SO_2 recovery and an acid plant, while line (c) indicates the two weak gas treatment options applied to the copper circuit options.

4. Together the three options indicated by lines (b) and (c) can be combined as shown by the tie lines (e) and (f) with each of the two Nickel 3 weak gas treatments resulting in six (2 x 3) combinations in addition to the two weak gas treatments shown by (a). Hence, line (d) represents a combined total of eight options.

TABLE 4.1

INCO'S PRIMARY AND SECONDARY ABATEMENT PROGRAMS - SO_2 BALANCE

PROGRAM #	OPTION	ABATEMENT PROGRAM DESCRIPTION	SO_2 EMISSIONS	REDUCTION IN SO_2 EMISSIONS FROM BASE CASE		SULPHUR FIXED IN SMELTER	SULPHUR FIXED IN SMELTER, TONNES SULPHUR PER DAY				ACTUAL SO_2 COLLECTED TONNES PER DAY		
			TONNES/DAY	TONNES/DAY	% OF BASE	% OF FEED SULPHUR	TOTAL	CONTAINED AS SO_2 GAS	AS SOLIDS		AT EACH STAGE OF OPTION	CUMULATIVE FOR OPTION	TOTAL[1] IN SMELTER
									Retained	Change From Base Case			
				[1766-(3)]	[(4) ÷ 1766] x 100	[(7) ÷ 1065] x 100	[(8)+(9)]	[(13) ÷ (2)]		[67.1 ± (9)]			[(8)x2]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
		1980 Inco Operations (Production Level 255 million lbs. of Nickel)	2080	-	-	-	-	-	-	-	-	-	-
		Existing Process, plus Pyrrhotite Rejection (Base Case)[2]	1766	-	-	17.1	182	114.5	67.1	-	-	-	229
I	1	CCM, plus Matte Processing	1146	620	35.0	46.2	492	424.5	67.1	-	620	620	849
IA	1 + A	CCM, Matte Processing, plus Regenerative Gas Treatment	1021	745	42.2	52.0	554	486.5	67.1	-	125	745	973
IB	1 + B	CCM, plus Matte Processing + Non-Regenerative Gas Treatment	1021	745	42.2	52.0	554	486.5	67.1	-	125	745	973

Notes:
[1] Total includes current recovery of SO_2 at the rate of 229 tonnes/day as liquid SO_2 product.
[2] Base Case includes planned increase in pyrrhotite rejection and total sulphur fixed in smelter of 182 tonnes per day.
[3] Nickel Production: 280 million lbs. of Nickel per year.
[4] Copper refinery SO_2 emissions are estimated to be less than 2 tonnes/day and are not included in sulphur dioxide balance.

TABLE 4.1 (continued)

INCO'S PRIMARY AND SECONDARY ABATEMENT PROGRAMS - SO_2 BALANCE

PROGRAM #	OPTION	ABATEMENT PROGRAM DESCRIPTION	SO_2 EMISSIONS	REDUCTION IN SO_2 EMISSIONS FROM BASE CASE		SULPHUR FIXED IN SMELTER	SULPHUR FIXED IN SMELTER, TONNES SULPHUR PER DAY				ACTUAL SO_2 COLLECTED TONNES PER DAY		
			TONNES/DAY	TONNES/DAY	% OF BASE	% OF FEED SULPHUR	TOTAL	CONTAINED AS SO_2 GAS	AS SOLIDS		AT EACH STAGE OF OPTION	CUMULATIVE FOR OPTION	TOTAL[1] IN SMELTER
									Retained	Change From Base Case [67.1 ± (9)]			
				[1766-(3)]	[(4) ÷ 1766] x 100	[(7) ÷ 1065] x 100	[(8)+(9)]	[(13) ÷ (2)]					[(8)x2]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	2	Inco's Roast Reduction Smelting (RRS)	853	913	51.7	59.9	638	600.0	38.4	-28.7	971	971	1200
II	1 + 2	Inco's RRS, plus CCM	243	1523	86.2	88.5	943	905.0	38.4	-28.7	610	1581	1810
IIC	1 + A + 2 + C	Inco's RRS, CCM plus Regenerative Weak Gas Treatment	24	1742	98.6	98.9	1053	1014.5	38.4	-28.7	219	1800	2029
IID	1 + B + 2 + D	Inco's RRS, CCM plus Non-Regenerative Weak Gas Treatment	24	1742	98.6	98.9	1053	1014.5	38.4	-28.7	219	1800	2039
	3	Outokumpu Flash Furnace (OFF) for Nickel Concentrate	928	838	47.4	56.4	601	560.2	40.6	-26.5	891.4	891.4	1120.4
III	1 + 3	OFF, plus CCM	297	1469	83.2	86.0	916	875.7	40.6	-26.5	631.0	1522.4	1751.4

Notes:

[1] Total includes current recovery of SO_2 at the rate of 229 tonnes/day as liquid SO_2 product.

[2] Base Case includes planned increase in pyrrhotite rejection and total sulphur fixed in smelter of 182 tonnes per day.

[3] Nickel Production: 280 million lbs. of Nickel per year.

[4] Copper refinery SO_2 emissions are estimated to be less than 2 tonnes/day and are not included in sulphur dioxide balance.

TABLE 4.1 (continued)

INCO'S PRIMARY AND SECONDARY ABATEMENT PROGRAMS - SO_2 BALANCE

PROGRAM #	OPTION	ABATEMENT PROGRAM DESCRIPTION	SO_2 EMISSIONS	REDUCTION IN SO_2 EMISSIONS FROM BASE CASE		SULPHUR FIXED IN SMELTER	SULPHUR FIXED IN SMELTER, TONNES SULPHUR PER DAY				ACTUAL SO_2 COLLECTED TONNES PER DAY		
			TONNES/DAY	TONNES/DAY	% OF BASE	% OF FEED SULPHUR	TOTAL	CONTAINED AS SO_2 GAS	AS SOLIDS		AT EACH STAGE OF OPTION	CUMULATIVE FOR OPTION	TOTAL[1] IN SMELTER
									Retained	Change From Base Case			
				[1766-(3)]	[(4) ÷ 1766] x 100	[(7) ÷ 1065] x 100	[(8)+(9)]	[(13) ÷ (2)]		[67.1 ± (9)]			[(8)x2]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
IIIE	1 + A + 3 + E	OFF, CCM, plus Regenerative Weak Gas Treatment	30	1736	98.3	98.6	1050	1009.3	40.6	-26.5	267.3	1789.7	2018.7
IIIF	1 + B + 3 + F	OFF, CCM, plus Non-Regenerative Weak Gas Treatment	30	1736	98.3	98.6	1050	1009.3	40.6	-26.5	267.3	1789.7	2018.7
IV	4	Inco's IORP using RRS*; SO_2 Emissions from Smelter Stack and IORP Stack (IRRA)	802	964	54.6*	58.0	618	600	17.8	-49.3	971	971	1200
			92	100	52.1*								
		Inco Total	894	1064	54.3	58.0	618	600	17.8	-49.3	971	971	1355

Notes:
[1] Total includes current recovery of SO_2 at the rate of 229 tonnes/day as liquid SO_2 product.
[2] Base Case includes planned increase in pyrrhotite rejection and total sulphur fixed in smelter of 182 tonnes per day.
[3] Nickel Production: 280 million lbs. of Nickel per year.
[4] Copper refinery SO_2 emissions are estimated to be less than 2 tonnes/day and are not included in sulphur dioxide balance.
* % of Base Case SO_2 Emissions from each Stack.

TABLE 4.1 (continued)

INCO'S PRIMARY AND SECONDARY ABATEMENT PROGRAMS - SO_2 BALANCE

PROGRAM #	OPTION	ABATEMENT PROGRAM DESCRIPTION	SO_2 EMISSIONS	REDUCTION IN SO_2 EMISSIONS FROM BASE CASE		SULPHUR FIXED IN IORP	SULPHUR FIXED IN IORP, TONNES SULPHUR PER DAY				ACTUAL SO_2 COLLECTED TONNES PER DAY		
			TONNES/DAY	TONNES/DAY	% OF BASE	% OF FEED SULPHUR	TOTAL	CONTAINED AS SO_2 GAS	AS SOLIDS		AT EACH STAGE OF OPTION	CUMULATIVE FOR OPTION	TOTAL IN IORP
									Retained	Change From Base Case			
				[192-(3)]	[(4) ÷ 192] x 100	[(7) ÷ 779] x 100	[(8)+(9)]	[(13) ÷ (2)]		[67.1 ± (9)]			[(8)x2]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
		IORP (Base Case)	192	-			681	677.5	4.2	-	-	-	1355
V	5	IORP Non-Regenerative Weak Gas Treatment (IORP)	19	173	90.0	98.6	768	764.0	4.2	-	173	179	1568

TABLE 4.2

INCO SELECTED ABATEMENT PROGRAMS IN COMBINATION - SUMMARY OF SO_2 REDUCTIONS AND CONTROL COSTS

Page 1 of 3

PROGRAM #	OPTION	ABATEMENT PROGRAM DESCRIPTION	REDUCTION IN SO_2 EMISSIONS FROM BASE CASE		CHANGE IN TOTAL SULPHUR FIXED	ACTUAL SO_2 FIXED	CAPITAL COST	OPERATING COSTS, MILLION ($)		BY-PRODUCTS TONNES PER DAY			DEVELOPMENT ENGINEERING AND CONSTRUCTION
			TONNES/DAY [1766-(3)]	% OF BASE [(4) ÷ 1766] × 100	TONNES/DAY (7) - 182	TONNES PER DAY	MILLION ($)	TOTAL	ADDITIONAL COST FOR GAS TREATMENT	LIQUID SO_2	SULPHURIC ACID	GYPSUM WASTE	TIME (YEARS)
	(1)	(2)	(4)	(5)	(14)	(12)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
		Existing Process, plus Pyrrhotite Rejection (Base Case)	-	-	-	-	-	-	-	229	-	-	-
I	1	CCM, plus Matte Processing	620	35.0	310	620	75.0	5.35	Base Cost*	-	951	-	2
IA	1 + A	CCM, Matte Processing, plus Regenerative Gas Treatment	745	42.2	372	745	150.7	10.32	4.97	-	1141	-	2
IB	1 + B	CCM, plus Matte Processing + Non-Regenerative Gas Treatment	745	42.2	372	745	143.5	11.10	5.75	-	951	335	2
	2	Inco's Roast Reduction Smelting (RRS)	913	51.7	456	971	246.5	32.12	Base Cost*	-	1486	-	4

Note: This Table is a continuation of Table 4.1 and columns which reappear are identified with the same number.
Capital and operating cost figures are in January 1982 Canadian dollars.
*This option could save Inco about $25 million per year in operating costs when compared with present nickel circuit operating costs of $57.1 million.

TABLE 4.2 (continued)

INCO SELECTED ABATEMENT PROGRAMS IN COMBINATION - SUMMARY OF SO_2 REDUCTIONS AND CONTROL COSTS

PROGRAM #	OPTION	ABATEMENT PROGRAM DESCRIPTION	REDUCTION IN SO_2 EMISSIONS FROM BASE CASE		CHANGE IN TOTAL SULPHUR FIXED	ACTUAL SO_2 FIXED	CAPITAL COST	OPERATING COSTS, MILLION ($)		BY-PRODUCTS TONNES PER DAY			DEVELOPMENT ENGINEERING AND CONSTRUCTION
			TONNES/DAY [1766-(3)]	% OF BASE [(4) ÷ 1766]	TONNES/DAY (7) - 182	TONNES PER DAY	MILLION ($)	TOTAL	ADDITIONAL COST FOR GAS TREATMENT	LIQUID SO_2	SULPHURIC ACID	GYPSUM WASTE	TIME (YEARS)
	(1)	(2)	(4)	(5)	(14)	(12)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
II	1 + 2	Inco's RRS, plus CCM	1523	86.2	761	1581	339.4	37.47	5.35	-	2420	-	4
IIC	1 + A + 2 + C	Inco's RRS, CCM plus Regenerative Weak Gas Treatment	1742	98.6	871	1800	483.2	46.71	9.24	-	2756	-	4
IID	1 + B + 2 + D	Inco's RRS, CCM plus Non-Regenerative Weak Gas Treatment	1742	98.6	871	1800	464.6	47.84	10.37	-	2420	589	4
	3	Outokumpu Flash Furnace (OFF) for Nickel Concentrate	838	47.4	419	891	271.0	35.65	Base Cost*	-	1365	-	2
III	1 + 3	OFF, plus CCM	1469	83.2	735	1522	346.0	41.0	5.35	-	2331	-	2
IIIE	1 + A + 3 + E	OFF, CCM, plus Regenerative Weak Gas Scrubbing	1736	98.3	868	1790	490.6	50.35	9.35	-	2740	-	2

Note: This Table is a continuation of Table 4.1 and columns which reappear are identified with the same number. Capital and operating cost figures are in January 1982 Canadian dollars.

* This option could save Inco about $21 million per year in operating costs when compared with present nickel circuit operating costs of $57.1 million.

TABLE 4.2 (continued)

INCO SELECTED ABATEMENT PROGRAMS IN COMBINATION - SUMMARY OF SO_2 REDUCTIONS AND CONTROL COSTS

Page 3 of 3

PROGRAM	OPTION	ABATEMENT PROGRAM	REDUCTION IN SO_2 EMISSIONS FROM BASE CASE		CHANGE IN TOTAL SULPHUR FIXED	ACTUAL SO_2 FIXED	CAPITAL COST	OPERATING COSTS, MILLION ($)		BY-PRODUCTS TONNES PER DAY			DEVELOPMENT ENGINEERING AND CONSTRUCTION
			TONNES/DAY [1766-(3)]	% OF BASE [(4) ÷ 1766] x 100	TONNES/DAY (7) - 182	TONNES PER DAY	MILLION ($)	TOTAL	ADDITIONAL COST FOR GAS TREATMENT	LIQUID SO_2	SULPHURIC ACID	GYPSUM WASTE	TIME (YEARS)
	(1)	(2)	(4)	(5)	(14)	(12)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
IIIF	1 + B + 3 + F	OFF, CCM, plus Non-Regenerative Weak Gas Scrubbing	1736	98.3	868	1790	470.9	52.2	11.22	-	2331	719	2
IV	4	Inco's IORP - RRS* Option (IRRA)	1064	54.3	436	971	430.0**	32.2	Base Cost***	-	1487	-	5
V	5	IORP Non-Regenerative Weak Gas Treatment (IORP)	173	90.0	86.5	173	41.0	5.47	-	-	-	464	1

Note: This Table is a continuation of Table 4.1 and columns which reappear are identified with the same number.
Capital and operating cost figures are in January 1982 Canadian dollars.

* This option also eliminates pyrrhotite roasting emissions by 150 tonnes/day.

** Capital and O/M costs are estimated.

*** This option could save Inco $25 million per year in operating costs similar to option 2 and it also avoids locating new markets for acid produced from nickel concentrate roaster off-gas.

TABLE 4.3

SUPPLEMENTARY ABATEMENT OPTIONS IN COMBINATION
SUMMARY OF SO_2 REDUCTIONS AND CONTROL COSTS

Page 1 of 5

Production Capacity - 280 million lbs. of Nickel Per Year.

APPLICABLE PROGRAM NO.	OPTION NO.	ABATEMENT TECHNOLOGIES AND COMBINATIONS	SO_2 EMISSIONS		SULPHUR DIOXIDE[1]		CAPITAL COSTS	OPERATING COSTS	BY-PRODUCT
			tonnes per day		tonnes per day		million ($)*	million ($)*	10^3tonnes /yr
		DESCRIPTION	IORP STACK	CC SMELTER STACK	EMISSIONS REDUCTION FROM BASE CASE	FIXED AS ACID OR SLUDGE			100% SULPHURIC ACID
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Base Case	192	1766	-	-			
I	1	CCM	192	1146	620	620	75.0	5.35	346.5
II	2	RRS	192	853	913	971	264.4	32.12[2]	542.7
III	3	OFF	192	928	838	891	271.0	35.65[2]	498.0
IV	4	Inco's IORP Option with RR (IRRA)	92	802	1064	971	430.0	32.12[2]	-215.7**
V	5	IORP, NRWGT for Pyrrhotite Roasting (IORP)	19	1766	173	173	41.0	5.47	-

Notes:
[1] Reduction in SO_2 emissions and SO_2 fixed may not be same in some cases due to differences in sulphur distribution in smelter which is related to process changes.
[2] These options could result in net savings in operating costs when compared with present operating costs for nickel circuit operation estimated to be $57.1 million per year.
* January 1982 Canadian dollars.
** Indicates decrease in acid production.
NRWGT: non-regenerative weak gas treatment.
RWGT: regenerative weak gas treatment.

TABLE 4.3 (continued)

Page 2 of 5

SUPPLEMENTARY ABATEMENT OPTIONS IN COMBINATION
SUMMARY OF SO_2 REDUCTIONS AND CONTROL COSTS

Production Capacity - 280 million lbs. of Nickel Per Year.

APPLICABLE PROGRAM NO.	OPTION NO.	ABATEMENT TECHNOLOGIES AND COMBINATIONS	SO_2 EMISSIONS		SULPHUR DIOXIDE[1]		CAPITAL COSTS	OPERATING COSTS	BY-PRODUCT
			tonnes per day		tonnes per day		million ($)*	million ($)*	10^3 tonnes /yr
		DESCRIPTION	IORP STACK	CC SMELTER STACK	EMISSIONS REDUCTION FROM BASE CASE	FIXED AS ACID OR SLUDGE			100% SULPHURIC ACID
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IA	6	CCM + RWGT	192	1021	745	745	150.7	10.32	416.4
IB	7	CCM + NRWGT	192	1021	745	745	143.5	11.10	346.5
	8	RRS + RWGT	192	757	1009	1067	332.5	36.38[2]	596.3
	9	RRS + NRWGT	192	757	1009	1067	321.2	36.73[2]	542.7
	10	OFF + RWGT	192	786	980	1033	340.0	39.99[2]	577.3
	11	OFF + NRWGT	192	786	980	1033	327.5	41.12[2]	498.0

Notes: [1] Reduction in SO_2 emissions and SO_2 fixed may not be same in some cases due to differences in sulphur distribution in smelter which is related to process changes.

[2] These options could result in net savings in operating costs when compared with present operating costs for nickel circuit operation estimated to be $57.1 million per year.

* January 1982 Canadian dollars.

NRWGT: non-regenerative weak gas treatment.

RWGT: regenerative weak gas treatment.

TABLE 4.3 (continued)

Page 3 of 5

SUPPLEMENTARY ABATEMENT OPTIONS IN COMBINATION
SUMMARY OF SO_2 REDUCTIONS AND CONTROL COSTS
Production Capacity - 280 million lbs. of Nickel Per Year.

APPLICABLE PROGRAM NO.	OPTION NO.	ABATEMENT TECHNOLOGIES AND COMBINATIONS	SO_2 EMISSIONS		SULPHUR DIOXIDE[1]		CAPITAL COSTS	OPERATING COSTS	BY-PRODUCT
			tonnes per day		tonnes per day		million ($)*	million ($)*	10^3 tonnes /yr
		DESCRIPTION	IORP STACK	CC SMELTER STACK	EMISSIONS REDUCTION FROM BASE CASE	FIXED AS ACID OR SLUDGE			100% SULPHURIC ACID
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	12	CCM + RRS	192	243	1523	1581	339.4	37.47[2]	883.0
	13	CCM + OFF	192	297	1469	1522	346.0	41.00[2]	851.0
	14	CCM + RRS + IORP	19	243	1696	1754	380.4	42.94[2]	883.0
	15	CCM + OFF + IORP	19	297	1642	1695	387.0	46.47[2]	851.0
IIC	16	(CCM + RRS) + RWGT	192	24	1742	1800	483.2	46.71[2]	1006.0
IID	17	(CCM + RRS) + NRWGT	192	24	1742	1800	464.6	47.84[2]	883.0
IIIE	18	(CMM + OFF) + RWGT	192	30	1736	1790	490.6	50.35[2]	1000.0

Notes: [1] Reduction in SO_2 emissions and SO_2 fixed may not be same in some cases due to differences in sulphur distribution in smelter which is related to process changes.

[2] These options could result in net savings in operating costs when compared with present operating costs for nickel circuit operation estimated to be $57.1 million per year.

* January 1982 Canadian dollars.
NRWGT: non-regenerative weak gas treatment.
RWGT: regenerative weak gas treatment.

SUPPLEMENTARY ABATEMENT OPTIONS IN COMBINATION
SUMMARY OF SO_2 REDUCTIONS AND CONTROL COSTS

Production Capacity - 280 million lbs. of Nickel Per Year.

APPLICABLE PROGRAM NO.	OPTION NO.	ABATEMENT TECHNOLOGIES AND COMBINATIONS	SO_2 EMISSIONS		SULPHUR DIOXIDE[1]		CAPITAL COSTS	OPERATING COSTS	BY-PRODUCT
			tonnes per day		tonnes per day		million ($)*	million ($)*	10^3tonnes /yr
		DESCRIPTION	IORP STACK	CC SMELTER STACK	EMISSIONS REDUCTION FROM BASE CASE	FIXED AS ACID OR SLUDGE			100% SULPHURIC ACID
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IIIF	19	(CMM + OFF) + NRWGT	192	30	1736	1790	470.9	52.20^2	851.0
	20	(CMM + RSS) + RWGT + IORP	19	24	1915	1973	524.2	52.18^2	1006.0
	21	(CMM + RRS) + NRWGT + IORP	19	24	1915	1973	505.6	53.31^2	883.0
	22	(CCM + OFF) + RWGT + IORP	19	30	1909	1963	531.6	55.82^2	1000.0
	23	(CCM + OFF) + NRWGT + IORP	19	30	1909	1963	511.9	57.67	851.0
	24	CCM + IORP	19	1146	793	793	116.0	10.82	346.5

Notes: [1] Reduction in SO_2 emissions and SO_2 fixed may not be same in some cases due to differences in sulphur distribution in smelter which is related to process changes.

[2] These options could result in net savings in operating costs when compared with present operating costs for nickel circuit operation estimated to be $57.1 million per year.

* January 1982 Canadian dollars.

NRWGT: non-regenerative weak gas treatment.

RWGT: regenerative weak gas treatment.

TABLE 4.3 (continued)

SUPPLEMENTARY ABATEMENT OPTIONS IN COMBINATION
SUMMARY OF SO_2 REDUCTIONS AND CONTROL COSTS

Page 5 of 5

Production Capacity - 280 million lbs. of Nickel Per Year.

APPLICABLE PROGRAM NO.	OPTION NO.	ABATEMENT TECHNOLOGIES AND COMBINATIONS	SO_2 EMISSIONS		SULPHUR DIOXIDE[1]		CAPITAL COSTS	OPERATING COSTS	BY-PRODUCT
			tonnes per day		tonnes per day		million ($)*	million ($)*	10^3 tonnes /yr
		DESCRIPTION	IORP STACK	CC SMELTER STACK	EMISSIONS REDUCTION FROM BASE CASE	FIXED AS ACID OR SLUDGE			100% SULPHURIC ACID
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	25	RRS + IORP	19	853	1086	1144	305.4	37.59[2]	542.7
	26	OFF + IORP	19	928	1011	1064	312.0	41.12[2]	498.0
	27	CCM + RWGT + IORP	19	1021	918	918	191.7	15.79[2]	416.4
	28	RRS + RWGT + IORP	19	757	1182	1067	373.5	41.86[2]	596.3
	29	OFF + RWGT + IORP	19	786	1153	1033	381.0	45.46[2]	577.3
	30	CCM + NRWGT + IORP	19	1021	918	918	184.4	16.57[2]	346.5
	31	RRS + NRWGT + IORP	19	757	1182	1067	362.2	42.20[2]	542.7
	32	OFF + NRWGT + IORP	19	786	1153	1033	368.5	46.55[2]	498.0

Notes: [1] Reduction in SO_2 emissions and SO_2 fixed may not be same in some cases due to differences in sulphur distribution in smelter which is related to process changes.

[2] These options could result in net savings in operating costs when compared with present operating costs for nickel circuit operation estimated to be $57.1 million per year.

* January 1982 Canadian dollars.

NRWGT: non-regenerative weak gas treatment.

RWGT: regenerative weak gas treatment.

APPENDIX 4.1

LIST OF TECHNICALLY FEASIBLE ABATEMENT PROGRAMS - INCO

Basic Programs

CCM - Copper Circuit Modifications with Matte Processing

RRS - Roast/Reduction Smelting (Nickel Circuit)

OFF - Outokumpu Flash Furnace (Nickel Circuit)

IORP - Iron Ore Recovery Plant with Non-regenerative Weak Gas Treatment

IRRA - Inco Roast/Reduction Alternative using the IORP

RWGT - Regenerative Weak Gas Treatment

NRWGT - Non-regenerative Weak Gas Treatment

APPENDIX 4.1 (continued)

LIST OF TECHNICALLY FEASIBLE ABATEMENT PROGRAMS - INCO[1]

Program	SO_2 REDUCED[2] TONNES	EMISSION LEVEL TONNES
CCM	620	1338
CCM + RWGT	745	1213
CCM + NRWGT	745	1213
RRS	913	1045
CCM + RRS	1523	435
CCM + RWGT + RRS	1658	300
CCM + NRWGT + RRS	1658	300
RRS + RWGT	1009	949
CCM + RRS + RWGT	1629	329
(CCM + RRS) + RWGT	1742	216
CCM + NRWGT + RRS + RWGT	1742	216
RRS + NRWGT	1009	949
CCM + RRS + NRWGT	1624	329
CCM + RWGT + RRS + NRWGT	1754	204
(CCM + RRS) + NRWGT	1754	204
OFF	838	1120
CCM + OFF	1469	489
CCM + RWGT + OFF	1583	395
CCM + NRWGT + OFF	1583	375

[1] Annual production of nickel and copper is 280 million lbs and 300 million lbs, respectively. Nickel production from Iron Ore Recovery Plant (IORP) is included in the 280 million lbs.

[2] The 'SO_2 Reduced' may vary by 10% due to changes in sulphur balances as components of programs are added.

APPENDIX 4.1 (continued)

LIST OF TECHNICALLY FEASIBLE ABATEMENT PROGRAMS - INCO[1]

Program	SO_2 REDUCED[2] TONNES	EMISSION LEVEL TONNES
OFF + RWGT	980	978
CCM + OFF + RWGT	1600	358
(CCM + OFF) + RWGT	1736	233
CCM + NRWGT + OFF + RWGT	1736	233
OFF + NRWGT	980	978
CCM + OFF + NRWGT	1600	358
CCM + RWGT + OFF + NRWGT	1725	233
(CCM + OFF) + NRWGT	1725	233
IORP (NRWGT)	173	1785
CCM + IORP	793	1165
CCM + RWGT + IORP	918	1040
CCM + NRWGT + IORP	918	1040
RRS + IORP	1086	872
CCM + RRS + IORP	1696	262
CCM + RWGT + RRS + IORP	1831	127
CCM + NRWGT + RRS + IORP	1831	127
RRS + RWGT + IORP	1182	776
CCM + RRS + RWGT + IORP	1802	156
(CCM + RRS) + RWGT + IORP	1927	31

[1] Annual production of nickel and copper is 280 million lbs and 300 million lbs, respectively. Nickel production from Iron Ore Recovery Plant (IORP) is included in the 280 million lbs.

[2] The 'SO_2 Reduced' may vary by 10% due to changes in sulphur balances as components of programs are added.

APPENDIX 4.1 (continued)

LIST OF TECHNICALLY FEASIBLE ABATEMENT PROGRAMS - INCO[1]

Program	SO_2 REDUCED[2] TONNES	EMISSION LEVEL TONNES
RRS + RNWGT + IORP	1182	776
CCM + RRS + RWGT + IORP	1802	156
CCM + RWGT + RRS + RNWGT + IORP	1927	31
(CCM + RRS) + NRWGT + IORP	1929	29
OFF + IORP	1011	947
CCM + OFF + IORP	1642	316
CCM + RWGT + OFF + IORP	1756	202
CCM + NRWGT + OFF + IORP	1756	202
OFF + RWGT + IORP	1153	805
CCM + OFF + RWGT + IORP	1773	185
CCM + RWGT + OFF + RWGT + IORP	1898	60
CCM + NRWGT + OFF + RWGT + IORP	1898	60
OFF + NRWGT + IORP	1153	805
CCM + OFF + NRWGT + IORP	1773	185
(CCM + OFF) + NRWGT + IORP	1898	60
IRRA	1064	894

[1] Annual production of nickel and copper is 280 million lbs and 300 million lbs, respectively. Nickel production from Iron Ore Recovery Plant (IORP) is included in the 280 million lbs.

[2] The 'SO_2 Reduced' may vary by 10% due to changes in sulphur balances as components of programs are added.

APPENDIX 4.2

EVALUATION OF CAPITAL COST ESTIMATES

This evaluation is based on a comparison of cost estimates for a roast/reduction smelting facility constructed in the existing smelter, with an acid plant and weak gas treatment.

The consultant's estimates of costs were based on the conceptual studies and did not include costs of demolition over those due to loss of production. They are order of magnitude costs with an accuracy of minus 10% to plus 50%, if all of the assumptions made are valid and the exclusions deliberately made are allowed for.

The estimates were limited by certain exclusions and by some assumptions, which were:

EXCLUSIONS FROM CAPITAL COST ESTIMATES

- Owner's administrative and supervisory expenses;
- Cost of land acquisition;
- Cost of financing and interest during construction;
- Capital cost escalation;
- Startup and commissioning costs;
- Insurance costs, except as provided by contractors to cover their own interests;
- License fees and royalties;
- Demolition, and removal of existing equipment;
- Plant services, on the assumption that existing services will be adequate for the modified plant (an exception is an electrical substation and transformers for the electric smelting furnaces for which costs are included).

ASSUMPTIONS MADE

- That existing equipment is used to deliver feed materials to the first unit in the various options and to handle products where these are essentially the same as in the existing facilities;
- That existing workshop, office buildings, laboratory facilities, and metal storage and shipping facilities are adequate. No allowance has been made for additions or modifications;

- That off-gases from the unit operations are cooled, dedusted and then ducted to a point where they are mixed with other gas streams or directed to a sulphur fixation facility. Allowances have been made for the cost of gas ductwork to the approximate plant locations shown in the conceptual layouts;

- That, where major new equipment is involved, an allowance has been made for housing the equipment in a new building.

The estimates for the major abatement program indicated that the total capital costs, including weak gas treatment, were of the order of $450 million to $500 million.

In the meantime, Inco had had studies of its own carried out both internally and by a consultant. Costs of between $700 million and $750 million had been developed. These are estimated costs only and for which Inco claims no greater accuracy than a factor of two and indicates that the accuracy could be even less.

Inco has provided access to the information contained in its studies and a review of both sets of costings has indicated the reasons for the apparent discrepancies. In view of the accuracy claimed for each estimate and of the different bases, no precise agreement can be expected.

In addition to extra costs for an acid plant at the smelter, designed with deliberate emphasis on reliability in order to ensure maintenance of operation and continuity of production, other costs arose from differences in the assumptions made and exclusions from the costings.

The Inco studies excluded:

- escalation costs;
- interest;
- loss of production

and included allowances for:

- demolition;
- feed lines and transport facilities where needed;
- structural additions required to support new installations;
- costs due to logistics of maintaining production during changeover to the new systems;
- additional modifications to the electrostatic precipitators and their ductwork.

The following major additional costs, which are offset by other smaller differences in detail and a difference in the weak gas treatment, account for the difference between the estimates.

		Million $*
1.	Inclusion of Feed Handling Costs	70
2.	Building Modification	90
3.	New Acid Plant	70
4.	Infrastructures, Support Service, etc.	50
	Total	$280

This comparison indicates that, by reason of the constraints placed upon them and as a result of the exclusions from the estimates, the Task Force studies have produced cost estimates which are low in most cases, although some itemized costs are reliable.

An attempt has been made in subsequent Chapters to evaluate and assess the impact of using the higher cost estimates of the roast/reduction and Outokumpu process options.

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* January 1982 Canadian dollars.

5. THE PRODUCTION PROCESS AT FALCONBRIDGE LIMITED: SOURCES OF EMISSIONS, PROCESS CHANGES AND ABATEMENT TECHNOLOGIES

Abstract

The basic steps in the Falconbridge operations at Sudbury are outlined in this Chapter, including the mill operations, in which unwanted rock and pyrrhotite are separated from the desirable metallic compounds, and the smelting operations, in which a nickel/copper sulphide matte is produced. Differences from the Inco operations are identified and the fate of the sulphur removed from the ore during processing is described.

It is noted that, apart from a small quantity of high grade copper concentrate which is sent to Inco Limited for treatment, a single nickel/copper concentrate is produced in the mills. Hence, there is only a single smelting circuit which produces a high grade nickel/copper matte which is refined in the Company's Norwegian refinery. In addition to this elimination of the matte processing and refining operations, the discard of pyrrhotite to the tailings areas means that no iron ore recovery or nickel oxide manufacturing processes are operated.

Simplified sulphur balances are shown in diagram form in Figures 5.2 and 5.4 and are also outlined in the text. Just over 50% of the sulphur in the ore is rejected in the tailings and pyrrhotite discards; 5.3% remains in the nickel/copper matte; 1.9% is discarded as slag; 22.7% is converted to sulphuric acid and 16.5% (35.5% of that in the smelter feed) is emitted to the atmosphere in weak off-gas streams and as fugitive emissions.

The mill operations are described and the two mills, the Strathcona, which produces 75% of the smelter's needs, and the Falconbridge mill are discussed.

The effect of smelter changes carried out in 1978 are related to a major reduction in SO_2 emissions to about 44% of the earlier levels. Only estimates of the fugitive SO_2 emissions are available and it is assumed, by comparison with Inco, that they comprise 1.4% of the stack emissions. Particulate emissions are noted in Table 5.1, but are based on one set of measurements made in 1979. The total quantities of particulate matter emitted are however relatively small and of minor importance.

The technologies available for increased emission reductions are reviewed and they include:

- increased pyrrhotite rejection;
- smelting process changes;
- strong SO_2 emissions treatment;
- weak gas stream treatment;
- reduction of fugitive emissions.

In view of the recent modernization of the Falconbridge smelter, only modifications to the existing fluid bed roasting/electric furnace smelting process, e.g. roast/reduction, have been considered for smelter process changes; other technologies have been assessed in the light of their availability, the stage of development reached and their cost effectiveness. A representative selection has been chosen for further evaluation in Chapter 6 and is listed in Table 5.2.

5.1 The Present Pyrometallurgical Process

5.1.1 Introduction

The ores mined and processed by Falconbridge in the Sudbury area are similar in their basic characteristics to the ores mined by Inco (described in Chapter 3). The copper, nickel and other valuable metals occur in sulphide minerals, primarily chalcopyrite and pentlandite. The iron sulphide mineral, pyrrhotite, is also abundant and it contains small but significant amounts of nickel both in solid solution and very finely disseminated. About 65% of the ore is made up of worthless rock-forming minerals, called gangue.

The basic steps in Falconbridge's process operations at Sudbury are:

- processing the ores in the mills, to separate the chalcopyrite and pentlandite from much of the pyrrhotite and from the gangue, which is sent to waste disposal areas; the separated product is a single nickel/copper concentrate;
- smelting the nickel/copper concentrate to produce a high grade nickel/copper matte which is shipped to Norway for refining.

Principal differences between the Falconbridge and Inco operations are:

- separate copper and nickel ore concentrates are not produced in Falconbridge's mills except for a small quantity of high grade copper concentrate which is shipped to Inco Ltd. for treatment;
- there is only a single circuit in the Falconbridge smelter and it produces a high grade nickel/copper matte;
- Falconbridge has no matte processing or refining operations at Sudbury; those processes are located at the Company's facilities in Norway;
- all pyrrhotite rejected in the mills is discarded in tailings areas; none of it is processed to recover iron oxide, nickel oxide or to manufacture sulphuric acid, as is done by Inco at its Iron Ore Recovery Plant.

5.1.2 Sulphur Balance in the Present Pyrometallurgical Process

A simple diagram of the metals production process at Falconbridge is given in Figure 5.1. The operations in which sulphur is eliminated from the process in one form or another occur in:

- the mills (concentrators); and
- the smelter.

Figure 5.2 is a simplified sulphur balance diagram which shows the proportion of the total amount of sulphur in the mined ore that leaves the process at various points. The form in which the sulphur is eliminated (solid, liquid, or gas) is noted on the diagram.

In 1981, approximately 2.8 million tonnes of ore, containing almost 320,000 tonnes of sulphur, were processed in the two Falconbridge mills. The concentrates leaving the mills contained less than one-half of this amount of sulphur. As shown in Figure 5.2, 52.4% of the sulphur entering the mills was rejected in the pyrrhotite and mill tails (waste rock) which are disposed of in tailings areas or are used for mine backfill (waste rock only). A further 1.2% of the sulphur in the ore is contained in the small amount of high grade copper concentrate which is not processed by Falconbridge.

Of the 46.4% of the sulphur which enters the smelter, about one-half (23.2%) combines with oxygen in the roasters to form SO_2 gas which is processed to produce sulphuric acid. Almost all of the sulphur ends up in the acid but up to 1% of the 23.2% entering the acid plant is emitted to the atmosphere in tail gas as SO_2.

Slightly more than one-third of the sulphur in the smelter feed (16.5% of the sulphur in the ore) is contained in low strength SO_2 gases which are formed in the smelting and conversion processes and are emitted directly to the atmosphere. The remaining 7.2% of the sulphur in the ore is contained in furnace slag (1.9%) and the product matte which is shipped to Norway for refining (5.3%).

5.2 Description of Present Process Operations and the Control of Sulphur Dioxide Emissions

In this section, each of the process operations which has a role in the elimination of sulphur contained in the ores is described, with emphasis on the aspects of the operations which contribute to SO_2 emissions or to their control.

5.2.1 The Mills

Falconbridge operates two mills in the Sudbury area. The Strathcona mill is located near Onaping, 35 km northwest of Sudbury, and the Falconbridge mill is located 20 km northeast of Sudbury, near the town of Falconbridge.

The Strathcona mill is the larger of Falconbridge's two mills. It is capable of processing 8,160 tonnes of ore per day and currently provides about 75% of the concentrate feed to the Falconbridge smelter. Most of the ore comes from the adjacent Strathcona underground mine, but substantial tonnages are also trucked in from smaller mines along the northern rim of the Sudbury Basin.

The smaller Falconbridge mill, with a capacity of 2,700 tonnes per day, supplies the remaining 25% of the concentrate feed and receives most of its ore from the Falconbridge Mine, although there is provision to receive ore by truck and rail from outside sources.

The basic objective of ore concentration in the mills is the same as described for Inco in Chapter 3: the separation of waste rock from the sulphide minerals and the removal from the concentrate of iron and sulphur which otherwise must be removed in the smelting process. The means of achieving this objective is a two stage process in which the sulphide minerals are first separated from the rock by froth flotation and then, pyrrhotite, having a low nickel concentration, is separated from the copper and nickel sulphides, chalcopyrite and pentlandite.

The four principal products of the ore concentration process are described in Figure 5.3.

5.2.2 The Smelter

Falconbridge completed a major smelter environmental improvement program in 1978. A significant reduction in sulphur dioxide emissions to the atmosphere was achieved by replacing the sinter plant/blast furnace smelting operations with fluid bed roasters and electric furnaces and by installing a sulphuric acid plant. A sulphur balance diagram for the smelter is given in Figure 5.4.

In the current process, nickel/copper concentrates are received in slurry form from the Strathcona and Falconbridge mills. The slurry is filtered to prepare a concentrate feed for the roasters. During roasting, 50% of the sulphur in the concentrate (23.2% of the sulphur in the ore) reacts with the oxygen in the fluidizing air in the roaster to form gaseous SO_2, which is discharged from the roaster in an off-gas stream averaging 10.7% SO_2.

Most of the roasted concentrate (calcine) is carried out of the roaster with the gas and is separated from the gas in cyclones, an evaporative cooler and an electrostatic precipitator. The roaster gas is directed to the sulphuric acid plant and the calcine is fed to the electric furnaces.

Smelting in the electric furnaces produces a nickel/copper furnace matte, which is subsequently converted in Pierce-Smith converters to produce a low iron matte. During these operations, about 40% of the iron in the concentrate is oxidized to iron oxide and removed as slag. Off-gases, diluted by inducted air, of relatively low SO_2 concentrations (1.2 to 1.9%) are collected from the furnaces and converters and are treated for removal of particulate matter before being discharged to the atmosphere. The product matte from the converters is crushed and shipped to Norway for refining.

The acid plant which treats the gases collected from the fluid bed roasters has a daily rated capacity of 1,180 tonnes of 100% sulphuric acid per day. The basic components of the plant are a gas cleaning section, a gas drying section, a sulphur dioxide (SO_2) to sulphur trioxide (SO_3) gas conversion section and a sulphur trioxide gas absorbing section. The plant was operating in 1981 at a production level of approximately 870 tonnes of acid per day.

Losses from the acid plant are in the range of 0 to 1% of the sulphur in the smelter feed and occur in the form of an SO_2 tail gas. A slurry effluent from the gas cleaning section is neutralized and pumped to a tailings disposal area.

5.3 Summary of Emissions from the Present Process

Emissions of 9.17 tonnes of SO_2 per tonne of nickel production in 1977 were reduced to about 3.95 tonnes of SO_2 per tonne of nickel production in 1980 and 1981. Annual emissions in 1980 were 122,000 tonnes, but since these emissions are related to production which was limited in 1980 to 30,590 tonnes of nickel, caution should be exercised when comparing them with other yearly emission quantities. For this reason, most of the sulphur and sulphur dioxide balances are quoted as percentages of input to the smelter.

Estimates of emissions of sulphuric acid, total particulate, iron, copper, nickel, lead and arsenic are presented in Table 5.1. These estimates are based on stack measurements performed in 1979. Other particulate emissions arise from sources such as the converters and are released at low level; no quantification is available. Comparison with particulate emissions from Inco's Copper Cliff smelter (Table 3.2) suggests that these should not exceed 50 tonnes/year which is a relatively small emission quantity. Measurements to estimate the level of fugitive SO_2 emissions from the smelter were not performed at this facility. In the absence of that information, it is assumed that these fugitive emissions account for about 1.4% of the stack emissions, as estimated for the Inco Copper Cliff smelter.

Hence, on the basis of annual SO_2 emissions from the Falconbridge smelter since 1978 (Table 2.1), annual average SO_2 fugitive emissions from this facility would range from about 3 to 5 tonnes per calendar day.

5.4 Opportunities for Further Reductions in Sulphur Dioxide Emissions

The principal abatement methodologies which can be considered as part of a strategy for further SO_2 emission reductions at Falconbridge are the same as described for Inco in Chapter 3:

A. Increased sulphur rejection in the milling process.

B. Smelting process changes to increase the proportion of SO_2 contained in gas streams of relatively strong SO_2 concentration.

C. Treatment of strong gas streams to remove SO_2.

D. Treatment of residual weak gas streams to remove SO_2.

E. Reduction of fugitive emissions.

Investigations of smelting process changes were made on the assumption that the fluid bed roasters and electric furnaces would remain as the basic elements of the Falconbridge smelter, with two levels of production, 63 million lb per year, the 1980 level, and 88 million lb per year, the rated capacity of the plant.

The abatement technologies which were selected as candidates for inclusion in overall SO_2 abatement programs at Falconbridge are listed in Table 5.2. The abatement programs themselves are described in Chapter 6.

One of the criteria for selecting the options was their stage of technical development, which can be broadly classified as:

Stage of Development	Example
Established	Hooding of Pierce-Smith Converters - Copper Smelting
Advanced Stage of development	Weak gas treatment
Early stage of development	Hooding of Pierce-Smith Converters - Nickel Smelting
Conceptual	Continuous converting

However, detailed testing and evaluation are required for each situation in order to determine the specific modifications suitable for application at Falconbridge.

5.5 Conclusions

In view of the major modification to the Falconbridge smelter in 1978 by which a significant reduction in SO_2 emissions was achieved, the immediately available technologies suitable for application to this smelter comprise modifications to the existing milling, roasting and smelting operations aimed at increasing the quantities of SO_2 emitted at each stage and their containment. No major redesign of the smelter is envisaged, although some large modifications to the equipment will be needed.

A reduction in the amount of ingress air at the Pierce-Smith nickel/copper converters to permit the manufacture of sulphuric acid from SO_2 produced by this source and the use of weak gas recovery systems to recover SO_2 from emissions with SO_2 concentrations lower than 4%, also warrant detailed consideration.

FIGURE 5.1

FALCONBRIDGE SMELTER - GENERAL FLOWSHEET (1979)

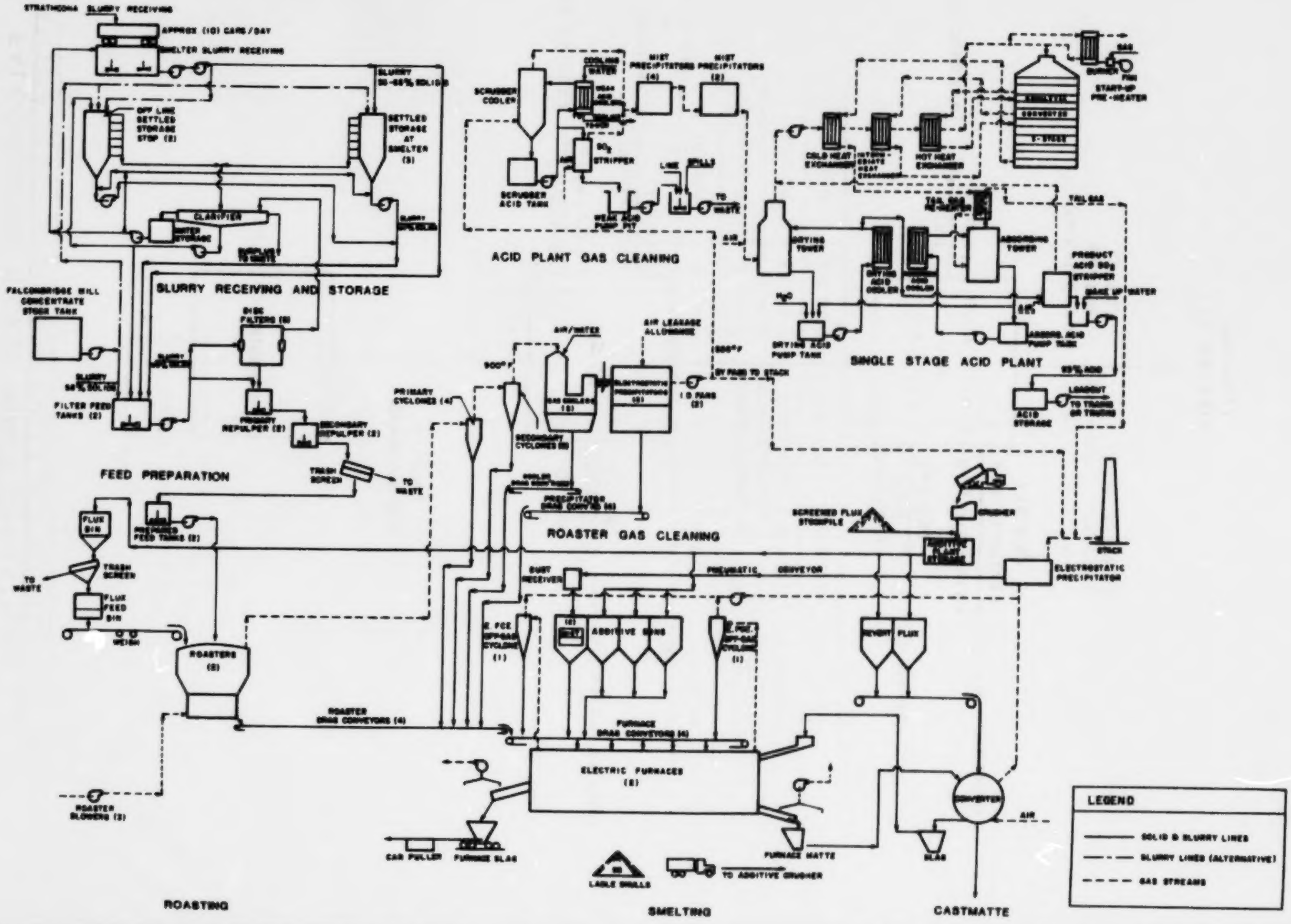
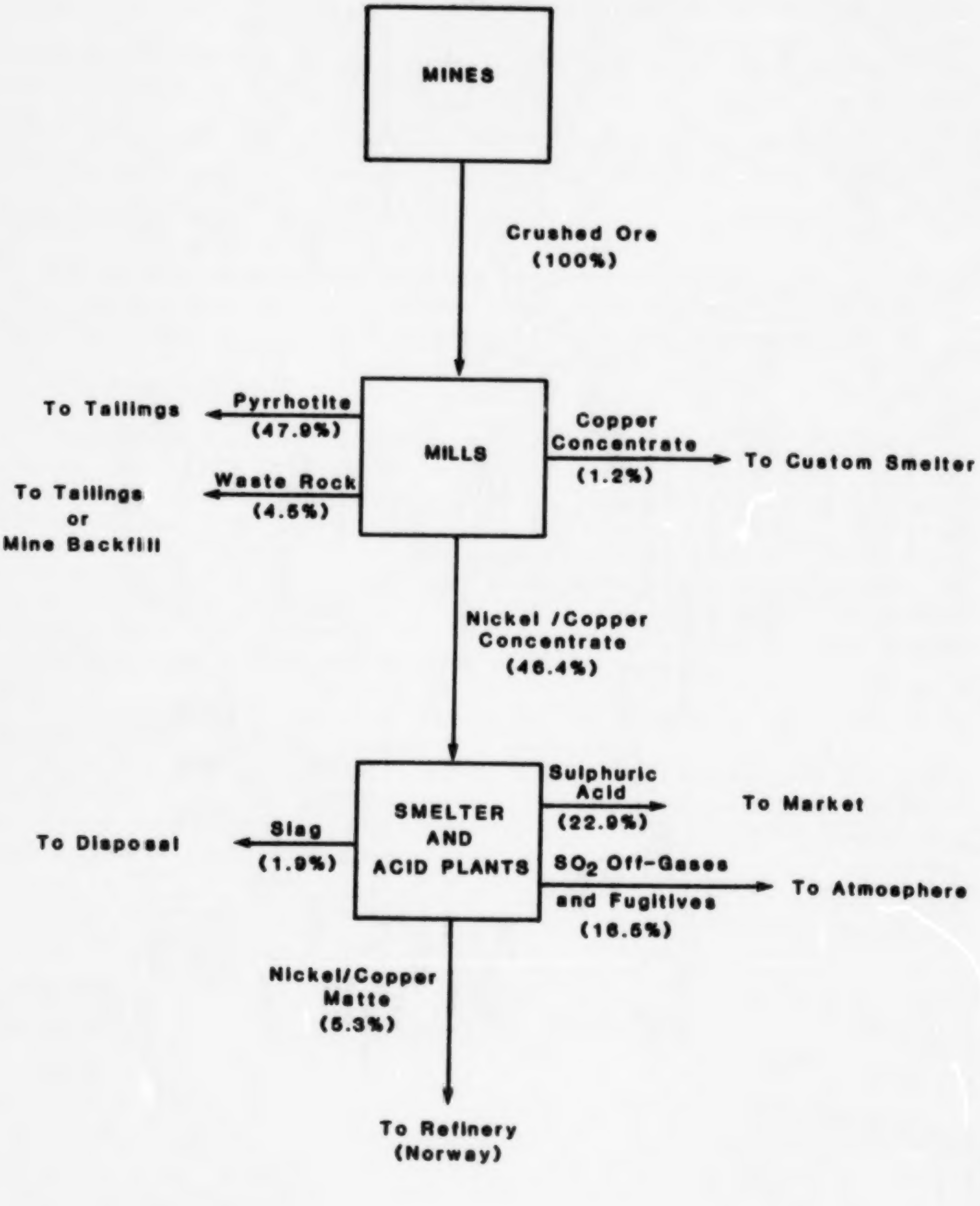

STRATHCONA SLURRY RECEIVING
APPROX (10) CARS / DAY
SMELTER SLURRY RECEIVING
SLURRY 50-65% SOLIDS
OFF LINE SETTLED STORAGE STOP (2)
SETTLED STORAGE AT SMELTER (3)
CLARIFIER
WATER STORAGE
SURPLUS TO WASTE
SLURRY RECEIVING AND STORAGE
FALCONBRIDGE MILL CONCENTRATE STOCK TANK
SLURRY 58% SOLIDS
FILTER FEED TANKS (2)
DISC FILTERS (8)
PRIMARY REPULPER (2)
SECONDARY REPULPER (2)
TRASH SCREEN
TO WASTE
FEED PREPARATION
FLUX BIN
PREPARED FEED TANKS (2)
TRASH SCREEN
TO WASTE
FLUX FEED BIN
WEIGH
ROASTERS (2)
ROASTER DRAG CONVEYORS (4)
ROASTER BLOWERS (3)
ROASTING
SCRUBBER COOLER
COOLING WATER
SCRUBBER ACID TANK
SO_2 STRIPPER
WEAK ACID PUMP PIT
LIME
SPILLS
TO WASTE
MIST PRECIPITATORS (4)
MIST PRECIPITATORS (2)
ACID PLANT GAS CLEANING
AIR
COLD HEAT EXCHANGER
INTERMEDIATE HEAT EXCHANGER
HOT HEAT EXCHANGER
CONVERTER
3-STAGE
GAS
BURNER
FAN
START-UP PRE-HEATER
DRYING TOWER
DRYING ACID COOLER
ACID COOLER
TAIL GAS RE-HEATER
ABSORBING TOWER
TAIL GAS
PRODUCT ACID SO_2 STRIPPER
MAKE UP WATER
H_2O
DRYING ACID PUMP TANK
ABSORB. ACID PUMP TANK
SINGLE STAGE ACID PLANT
93% ACID
ACID STORAGE
LOADOUT TO TRAINS OR TRUCKS
PRIMARY CYCLONES (4)
900° F
SECONDARY CYCLONES
AIR/WATER
GAS COOLERS (2)
AIR LEAKAGE ALLOWANCE
ELECTROSTATIC PRECIPITATORS (2)
I D FANS (2)
BY PASS TO STACK
PRECIPITATOR DRAG CONV'RS (4)
ROASTER GAS CLEANING
SCREENED FLUX STOCKPILE
CRUSHER
ADDITIVE PLANT STORAGE
STACK
DUST RECEIVER
PNEUMATIC CONVEYOR
ELECTROSTATIC PRECIPITATOR
E. FCE OFF-GAS CYCLONE (1)
ADDITIVE BINS
E. FCE OFF-GAS CYCLONE (1)
REVERT
FLUX
FURNACE DRAG CONVEYORS (4)
ELECTRIC FURNACES (2)
CONVERTER
AIR
CAR PULLER
FURNACE SLAG
LADLE SKULLS
TO ADDITIVE CRUSHER
FURNACE MATTE
SLAG
SMELTING
CASTMATTE
LEGEND
SOLID & SLURRY LINES
SLURRY LINES (ALTERNATIVE)
GAS STREAMS

FIGURE 5.2

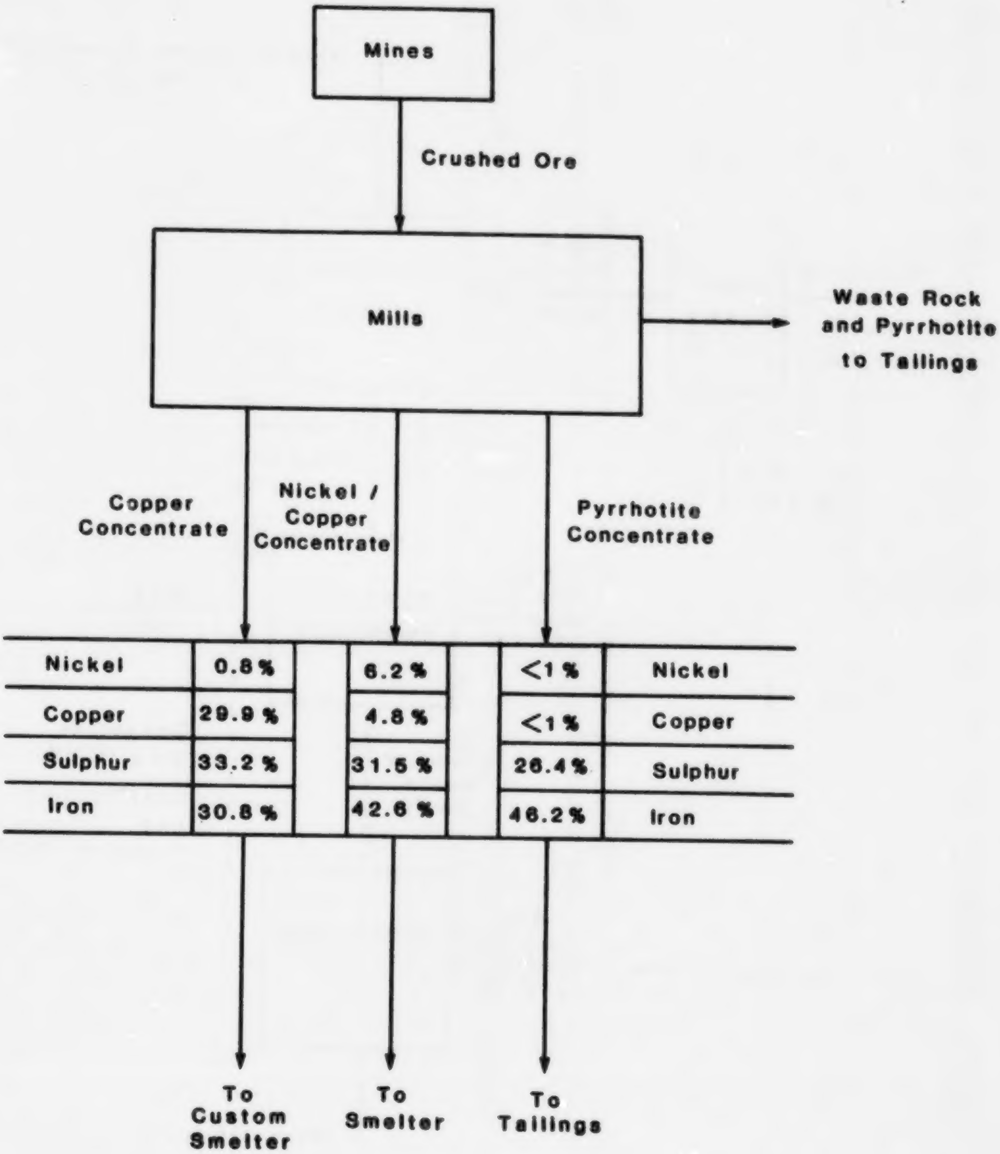
SIMPLIFIED SULPHUR BALANCE- EXISTING (1981) FALCONBRIDGE NICKEL MINES OPERATIONS*


MINES
Crushed Ore
(100%)
To Tailings
Pyrrhotite
(47.9%)
MILLS
Copper
Concentrate
(1.2%)
To Custom Smelter
To Tailings
or
Mine Backfill
Waste Rock
(4.5%)
Nickel /Copper
Concentrate
(46.4%)
Sulphuric
Acid
(22.9%)
To Market
To Disposal
Slag
(1.9%)
SMELTER
AND
ACID PLANTS
SO2 Off-Gases
and Fugitives
(16.5%)
To Atmosphere
Nickel/Copper
Matte
(5.3%)
To Refinery
(Norway)

*Percentage Sulphur of the Mined Ore

FIGURE 5.3

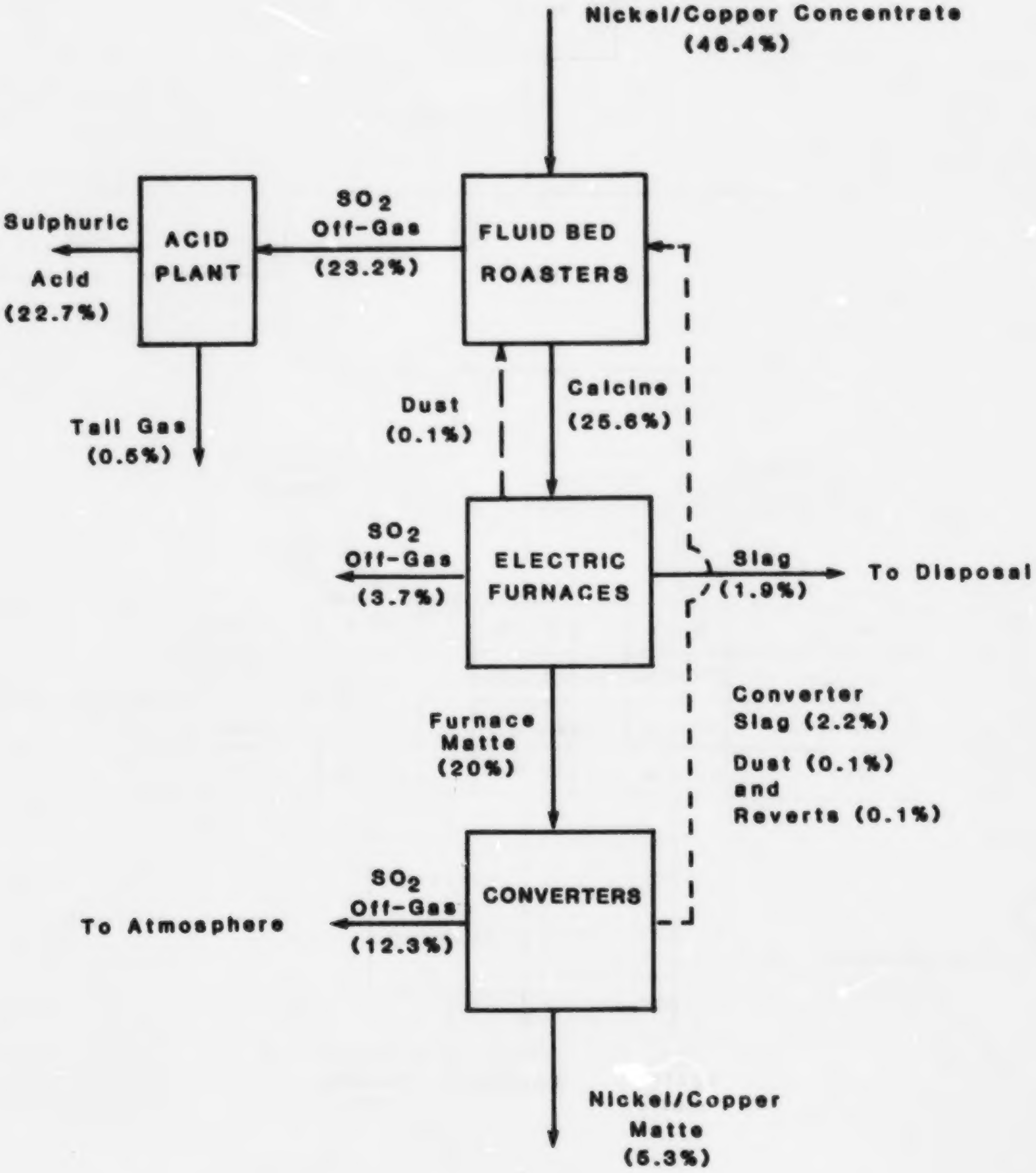
COMPOSITION OF FALCONBRIDGE ORE CONCENTRATES


Mines
Crushed Ore
Mills
Waste Rock and Pyrrhotite to Tailings
Copper Concentrate
Nickel / Copper Concentrate
Pyrrhotite Concentrate
To Custom Smelter
To Smelter
To Tailings

	Copper Concentrate	Nickel / Copper Concentrate	Pyrrhotite Concentrate	
Nickel	0.8 %	6.2 %	<1 %	Nickel
Copper	29.9 %	4.8 %	<1 %	Copper
Sulphur	33.2 %	31.5 %	26.4 %	Sulphur
Iron	30.8 %	42.6 %	46.2 %	Iron

FIGURE 5.4

SIMPLIFIED SULPHUR BALANCE- FALCONBRIDGE SMELTER (1981)*


Nickel/Copper Concentrate (46.4%)
Sulphuric Acid (22.7%)
ACID PLANT
SO_2 Off-Gas (23.2%)
FLUID BED ROASTERS
Tail Gas (0.5%)
Dust (0.1%)
Calcine (25.6%)
SO_2 Off-Gas (3.7%)
ELECTRIC FURNACES
Slag (1.9%)
To Disposal
Furnace Matte (20%)
Converter Slag (2.2%)
Dust (0.1%) and Reverts (0.1%)
To Atmosphere
SO_2 Off-Gas (12.3%)
CONVERTERS
Nickel/Copper Matte (5.3%)

*Percentage Sulphur of the Mined Ore

TABLE 5.1

AVERAGE YEARLY EMISSIONS (TONNES) OF MAJOR POLLUTANTS FROM FALCONBRIDGE LIMITED

SOURCE	SO_2	SULPHURIC ACID	TOTAL PARTICULATE	IRON	COPPER	NICKEL	LEAD	ARSENIC
191 Meter Smelter Stack*	173,000	438	865	98	11	9.6	13.4	6.4

*SO_2 emission estimates were obtained from mass balance calculations for the period 1973 to 1981 and include low level emissions (estimated at 1.4% of stack emissions). Emission estimates for the other pollutants were obtained from stack measurements performed in 1979.

Source of Data: Ozvacic, V., Emissions of Sulphur Oxides, Particulates and Trace Elements In The Sudbury Basin, Ontario Ministry of the Environment, Sudbury Environmental Study, Report No. SES 008/82 (1982).

TABLE 5.2

ABATEMENT TECHNOLOGIES SELECTED FOR FALCONBRIDGE SO_2 ABATEMENT PROGRAMS

A. SULPHUR REJECTION

	Process	Status
1.	Increased Pyrrhotite Rejection in the Mills	Available Established

B. PYROMETALLURGICAL PROCESSES YIELDING STRONG SO_2 OFF-GAS STREAMS

	Process	Status
1.	Increased Roasting	Available Advanced
2.	Roast/Reduction Smelting	Under development by Inco Advanced
3.	Hooding of Pierce-Smith Converters and blending with roaster emissions	Available Early

C. METHODS OF SULPHUR DIOXIDE RECOVERY FROM STRONG GAS STREAMS (over 4% SO_2)

	Process	Status
1.	Sulphuric Acid Production	Available Established

D. METHODS OF SULPHUR DIOXIDE RECOVERY FROM WEAK GAS STREAMS (less than 4% SO_2)

	Process	Status
Regenerative Processes		
1.	Citrate (Flakt-Boliden) Process	Available Advanced
Non-Regenerative Processes		
1.	Double Alkali Process	Available Advanced

6. ABATEMENT PROGRAMS - FALCONBRIDGE LIMITED

Abstract

The technologies selected as candidates for inclusion in the Falconbridge control options are combined in eight different abatement programs. These programs are described and assessed with respect to their capability of reducing emissions of sulphur dioxide, their costs, their production of wastes and/or marketable by-products and their availability for implementation.

The process changes examined for Falconbridge are increased rejection of pyrrhotite, an increased degree of roasting and roast/reduction smelting (similar to the Inco version).

The first process change results in a reduction in the amount of sulphur in the concentrate and hence, in a reduction in the SO_2 emissions. The other two processes give rise to increased SO_2 emissions from the roasting process but permit their containment in acid plants and their conversion to acid. Three other programs are concerned with containment of the weaker off-gas streams and removal of SO_2 in a recoverable form such as acid or concentrated SO_2 or in a disposable form such as gypsum.

Combining the pyrrhotite rejection and increased roasting processes with weak gas treatment increases the number of options examined to a total of eight. Two production levels are examined, 63 million lb per year of nickel (the 1981 actual level) and 88 million lb per year of nickel. The former is the anticipated average level of production during the next five years; the latter is the current design capacity of the smelter and has been employed in case the Company wishes to ensure that the current design level can be maintained.

The emission reductions achievable range from 34% to 93% at capital costs which may be as high as $62 million at design production rates. The majority of the options cost about $45 million at 1981 production rates and $50 million at design capacity. All can be implemented within five years.

A summary of the abatement programs considered for Falconbridge is presented in Table 6.1.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

6.1 Introduction

6.1.1 Abatement Program Concept

Eight abatement programs which employ one or more of the candidate abatement technologies (described in Chapter 5) to effect reductions in SO_2 and other emissions at Falconbridge are discussed. As in the case of Inco, the programs described here are not the only possible combinations of the various technologies. However, the range of choices is narrower for Falconbridge because of the major improvements which were made to the smelter in the late 1970's and because Falconbridge has fewer process operations and sources of SO_2 emissions.

In this Chapter, each abatement program is described in terms of its:

- impact on emissions of SO_2 and other pollutants;
- capital and operating costs (expressed in January 1982 Canadian dollars);
- length of time required for development, engineering and construction;
- production of potentially marketable by-products, e.g. sulphuric acid and gypsum;
- impact on other waste discharges from the process operations (e.g. tailings, slag, unmarketable by-products) and on waste disposal costs.

Subsequent Chapters deal with the environmental, socio-economic and financial impacts which would result from implementation of the abatement programs.

6.1.2 Principal Assumptions Underlying All Abatement Programs

Two reference levels of production have been used in describing the Falconbridge abatement programs, 63 million lb per year of nickel and 88 million lb per year of nickel. The former level is approximately equal to actual 1981 production, while the latter is the estimated maximum throughput of the smelter. The 63 million lb annual production level is a useful reference because it is roughly the level of expected output by Falconbridge over the next five years. This production rate requires a concentrate feed of 1,290 tonnes/operating day and gives rise to an uncontrolled emission rate of 690 tonnes of SO_2/operating day, currently controlled to 287 tonnes/operating day. The rationale for including the 88 million lb level as well is that, in looking to future production levels, the Company may wish to ensure that any changes to the smelter would maintain the current design capacity, which for some abatement programs will incur higher capital costs than if the changes were designed to accommodate only the current level of production.

Estimates of capital and operating costs are given for each abatement program. The basis of the capital costs is essentially the same as for Inco. Costs are based on conceptual plant arrangements, lists of major equipment and budget price quotations for selected plant or equipment items. An allowance was made for construction field indirect costs, engineering and construction management fees. A separate contingency (undefined costs) item was not included in the estimates. The capital cost estimates are regarded as being accurate within a range of plus 50% and minus 10%.

The incremental operating costs (labour, materials, energy) were estimated directly for each abatement program (which was not possible for Inco). The operating cost estimates are direct operating costs for battery limit production facilities and technical support, offices, laboratories and equipment needed for production such as assaying and process control. No disagreement with the cost estimates was expressed by Falconbridge, other than with regard to the direct acid manufacturing from converter gases. This arose from disagreement with the strength of the off-gases which could be achieved by close-hooding of the nickel/copper converters. Falconbridge believed that the maximum achievable SO_2 concentrations would be 4%. This would result in higher costs for the plant and its operation.

6.2 Description of Abatement Programs

Eight abatement programs are described which cover a wide range of capital costs and SO_2 emission reductions. The control strategies embodied in these programs include rejection of more sulphur before the smelting stage; changes in the smelting process to eliminate more sulphur in strong SO_2 off-gases which are more amenable to control than weak gases; and treatment of strong and weak gases to recover sulphur from the gas stream which is emitted to the atmosphere.

A number of other options were considered, but were rejected because either they appeared to have no cost advantages or their technical development was not well enough advanced. As a general guideline, processes which were unlikely to be available within five years were not accepted as practicable options. This cutoff time was chosen since it is believed that the conception, design and initial development of other new control methods could arise in a period of five years and render obsolete schemes which had not by then been initiated. Further, any method still five years away from being accepted as "available", could easily be found to be unsuitable. The resultant potential for yet further delay prohibited the inclusion of such an option from consideration in the present context.

6.2.1 Abatement Program I: Increased Pyrrhotite Rejection

6.2.1.1 Modifications to Process Operations

The elements of Programs I and IA are shown schematically in Figures 6.1 and 6.2. Program I involves changes in the mills to alter the ore concentration process, while Program IA includes Program I plus treatment of weak gases from the furnaces and converters.

Increasing the grade, or nickel to sulphur ratio, in smelter concentrates is a process which both Falconbridge and Inco have already adopted in order to reduce smelting costs and sulphur dioxide emissions. In 1981, Falconbridge smelted a concentrate (6.2% nickel, 4.8% copper) containing 46% of the sulphur in the ore. It is believed practical to increase the nickel content to 8.5%, corresponding to a concentrate containing 32% of the sulphur in the ore, through increased pyrrhotite rejection.

Increased pyrrhotite rejection can be achieved in the existing mills by changing the processes and utilizing, for the most part, the existing equipment. Process changes may include the following:

- adjusting the split between rougher and scavenger flotation to recover less in the rougher section;
- making changes in flotation reagents to obtain more effective separation of pentlandite from pyrrhotite;
- finer regrinding of middlings (nickel/copper concentrate recovered from pyrrhotite-rich fractions with recoverable copper and nickel still present).

Increased pyrrhotite rejection would result in a 27% decrease in sulphur in the smelter feed but a 34% decrease in sulphur dioxide emissions from the smelter stack. The higher percentage reduction in the stack emissions can be largely attributed to the fact that, with the higher grade smelter feed, a higher proportion of the sulphur in the feed would remain in the matte and correspondingly less would go to the stack.

It is estimated that an additional 6.5% by weight of ore must be mined and milled to maintain nickel production at 63 million lb per yr. The grade of concentrate is increased from 1981 levels to 8.5% nickel.

Only minor modifications are required in the mills, smelter and acid plant to implement increased pyrrhotite rejection at 1981 production rates. To produce at a rate of 88 million lb per yr of nickel would require a 10% expansion of milling capacity.

An important impact of more pyrrhotite rejection would be increased losses (to tailings and slag) of nickel, copper, cobalt and precious metals. Table 6.2 shows the estimated impact of increased pyrrhotite rejection on nickel, cobalt and copper recovery. Data were not available to prepare a similar estimate for the recovery of precious metals.

The impacts on costs are not only related to production costs and the costs of mining the additional ore, but are also dependent on the extent to which the ore reserves are more rapidly depleted by the increased quantity and higher quality of the ores mined. These costs have not been quantified in the current evaluation; however, they may be of a magnitude to reduce or exceed the cost savings in other areas of the operation.

Program IA includes not only the pyrrhotite rejection, but also a system for transforming weak SO_2 off-gases from the electric furnaces and the converters into strong SO_2 gases which can be treated in an acid plant. The particular system included in this program is the Flakt-Boliden process. Converter and electric furnace gases would be cleaned and then routed to a Flakt-Boliden scrubber plant where they would be cleaned further and treated with a citrate solution for the absorption of sulphur dioxide. The citrate solution will subsequently be heated to produce sulphur dioxide which could be converted to sulphuric acid in the acid plant.

At the 63 million lb per year nickel production level, the existing Falconbridge acid plant has enough capacity to treat the additional SO_2 gases, but at the 88 million lb level, a new acid plant would have to be constructed.

6.2.1.2 Impact on Sulphur Dioxide and Other Emissions

Programs I and IA would reduce SO_2 emissions to approximately 66% and 9% of present levels, respectively, as shown below:

Program	SO_2 Emissions (tonnes/day) 63 million lb/yr	88 million lb/yr
Existing Process	287	406
I	189	267
IA	25	36

The greater amount of gas cleaning which would occur in connection with acid making would reduce particulate emissions to some extent. Emissions from the electric furnace, which are presently being cleaned by an electrostatic precipitator, might be reduced by as much as 70%, while ducted emissions from the converter are expected to be reduced to about 25% of the current level. The total quantity collected has not been estimated because currently there is a lack of information about particulate emissions for specific sources.

Neither program would have any impact on the working area environment.

6.2.1.3 Capital and Operating Costs

Program I does not require any capital expenditure at the 63 million lb per year production level, but at the 88 million lb per year level, about $3.5 million would have to be spent to expand the Strathcona mill.

Increased operating costs in the mills are largely confined to tonnage-dependent items such as operating and maintenance, supplies and power. However, these cost increases are more than offset by savings in concentrate shipping charges from Strathcona to the Falconbridge Smelter.

In the smelter, there are modest decreases in costs because of the lower tonnages of concentrate treated. Program I would also have lower acid plant costs as a result of smaller amounts of SO_2 off-gas from the fluid bed roasters.

While the net effect of these changes is estimated to result in decreased operating costs ($2.8 million and $4.2 million per year less, at the 63 million lb and 88 million lb production levels, respectively), it has not been possible to estimate the costs related to the mining of higher tonnages of ore. These costs could reduce, or exceed, the cost savings in other areas of the operation.

Increased pyrrhotite rejection changes the relative amounts of nickel, copper and cobalt recovered from the ores. At the 63 million lb and 88 million lb per year production levels of nickel, copper recovery increases by 1,114 tonnes/year (1.8×10^6 lb/yr) and 1,318 tonnes/year (2.3×10^6 lb/yr), respectively. Cobalt recovery is unchanged (Table 6.2).

Considering the production of metals in the matte, by definition, nickel output from the smelter is not changed by increased pyrrhotite rejection. However, copper production increases by 1,100 tonnes/year and 1,600 tonnes/year for the production of 63 and 88 million lb per year of nickel, respectively. Cobalt output increases by 105 tonnes/year and 170 tonnes/year at the 63 and 88 million lb per year nickel production levels. The increased copper recoveries are attributed to lower copper losses, relative to nickel, in concentration. Increased cobalt recoveries are due to much lower cobalt losses in slag with higher grade feed to the smelter.

Additional modifications to the smelter, the Flakt-Boliden scrubbing plant, plus new acid plant capacity (88 million lb level only) result in capital cost estimates of $28 million and $35 million for Program IA at the 63 million lb and 88 million lb production levels, respectively. Corresponding incremental operating costs are $6.0 million and $9.0 million per year.

6.2.1.4 By-Products of Emission Reduction

Program IA would result in the production of sulphuric acid, in addition to Falconbridge's current acid production, as follows:

Production Level	Sulphuric Acid (tonnes/day)
63 million lb	88
88 million lb	124

6.2.1.5 Development, Engineering and Construction Time

No significant amount of time would be required to make adjustments to the smelter and acid plant to handle highe grade feed. It would require about 18 months, after a decision is made, to carry out the engineering and construction work for an expansion of the Strathcona Mill.

For Program IA, the overall time required to design, procure and erect the Flakt-Boliden scrubbing plant is estimated at 18 months. An initial development period of 18 months might be required.

6.2.2 Abatement Program II: Increased Roasting of Nickel/Copper Concentrate

6.2.2.1 Modifications to Process Operations

The elements of Programs II and IIA are shown schematically in Figures 6.3 and 6.4. Program II is essentially a change in the operation of the fluid bed roasters and Program IIA includes the same weak gas treatment system as in Program IA.

Normal practice at Falconbridge has been to eliminate 45% to 50% of the sulphur in the concentrate during fluid bed roasting. With relatively simple changes in the roasters, it should be possible to increase the degree of roast to eliminate 65% of the sulphur. The additional sulphur dioxide gas formed during roasting is fixed as sulphuric acid in the same way as roaster gases are now treated.

The existing roasters have sufficient capacity to process concentrates equivalent to a production level of 63 million lb of nickel per year at 65% sulphur elimination. However, higher roasting temperatures arising during this extended roasting will require modifications of the roaster system.

The combustion air inlet ports will need to be made from stainless steel, while the calcine collection and recycling system, the exhaust ducts and the cooler tower domes will have to be lined with refractory material.

Since the existing roaster capacity is inadequate to handle the concentrates at the 88 million lb per year nickel production rate, a new roaster line will also be required. The new roaster line will need to be sized to have a capacity of 60% of each existing line and to be designed to allow operation at the higher temperatures.

The consequences of a higher degree of roast are a greater smelting burden on the electric furnaces, less converting and higher losses of metals in the slag.

No modifications to the smelting furnaces will be needed at either production rate.

Estimated losses are as follows:

Production Level	Increase in Metal Losses to Slag (tonnes/yr)		
	Nickel	Copper	Cobalt
63 million lb	300	200	56
88 million lb	300	250	100

Acid plant modifications for the 63 million lb per year nickel production level are not required. However, at the higher production level, it will be necessary to increase the capacity of the plant to remove heat from the gas cleaning section and to reduce pressure drop through the plant. The latter will probably require changes to the catalyst and to the way in which it is packed and supported in the tower.

The weak gas treatment system employed in Program IIA is basically the same as that described for Program IA.

6.2.2.2 Impact on Sulphur Dioxide and Other Emissions

With the additional roasting and acid production in Program II, about 38% less sulphur dioxide will be emitted to the atmosphere from the smelter stack. Emissions drop from 287 tonnes/day to 178 tonnes/day at the 63 million lb per year nickel production level and from 406 tonnes/day to 252 tonnes/day at the 88 million lb production level.

With Program IIA, SO_2 emissions would drop to 32 and 44 tonnes/day at the 63 million lb and 88 million lb per year production levels respectively, or to about 11% of the emissions from the existing process.

Programs II and IIA would both result in some improvement in the working environment in the converter aisle, since the increased roasting of the concentrate drives off more sulphur, leaving less to be eliminated in the converters. Reductions in particulate emissions would be similar to those obtained in Program IA.

6.2.2.3 Capital and Operating Costs

Estimated capital costs for Program II are $4.5 million at the 63 million lb per year production level and $22 million at the 88 million lb level. The large difference between the two costs is accounted for by the new roaster needed to handle the increased roast at the higher production level.

Capital costs for Program IIA are $43 million and $62 million for the 63 million lb and 80 million lb annual production levels respectively.

Incremental operating costs for the two programs are estimated as follows:

Abatement Program	63 million lb	88 million lb
II	$0.4 million	$1.2 million
IIA	$10.6 million	$14.4 million

6.2.2.4 By-Products of Emission Reduction

Both Programs II and IIA increase the amount of strong SO_2 off-gases to be treated in the acid plant. The quantities of acid produced (additional to current production) are:

	Sulphuric Acid (tonnes/day)	
Abatement Program	63 million lb	88 million lb
II	182	254
IIA	418	591

6.2.2.5 Development, Engineering and Construction Time

Approximately six months are required to carry out further development, design and engineering work. Changes to the existing roasters could be completed about nine months later. Construction of the additional roasting line needed to accommodate the 88 million lb annual production level would require two years after completion of engineering.

The time to complete Program IIA would range from one and one half to three years, depending on the length of development time required for the Flakt-Boliden weak gas treatment process, and would be a minimum of two and one half years for the 88 million lb per year production level.

6.2.3 Abatement Program III: Roast/Reduction Smelting

6.2.3.1 Modifications to Process Operations

Roast/reduction smelting is an option that requires major changes at Falconbridge. This process would utilize the same roasting and electric furnace smelting circuit, but would involve more extensive roasting at much higher operating temperatures and higher electric furnace temperatures. Inco has a version of this technique under evaluation at its Thompson operation.

The key features of this process include the elimination of about 80% of the feed sulphur during roasting and the addition of large amounts of coke during subsequent electric furnace smelting. The coke reduces the large amount of nickel, copper and cobalt oxides which are formed during roasting and ensures that metal losses to slag are acceptable.

Converting primarily oxidizes the iron content of the furnace matte, instead of oxidizing sulphur, and results in low sulphur off-gases. Total sulphur emissions to the atmosphere from the two smelting steps are expected to be in the order of 5% of sulphur in the smelter feed.

In Falconbridge's case, roasting to 80% sulphur elimination requires a limited air supply to ensure that the formation of metallic sulphates in the calcine does not increase unacceptably and thus, results in higher processing temperatures which have not yet been determined.

These higher roasting temperatures will require the following modifications to the roasters in order that they will be able to withstand the higher temperature and increased erosion problems in a similar way to those modifications required for Program II:

- an additional roaster line for both levels of nickel production;
- electric furnace modifications to enable the equipment to withstand increased matte temperatures in the range of 130°C to 180°C.

Roast/reduction smelting would reduce nickel and cobalt losses to slag, when compared with the existing process, but would result in higher losses of copper. Losses (gains) are estimated as follows:

Production Level	Increase (Decrease) in Metal Losses to Slag		
	Nickel	Copper (tonnes/year)	Cobalt
63 million lb	(-)*	600	(186)
88 million lb	(-)*	860	(240)

---

* Information not available.

New acid plants are required for both levels of production. Their capacities are about 226 and 317 tonnes/day of 100% acid, respectively. It is assumed that the weak acid neutralizing system can be upgraded and shared by the existing and new plants. The acid storage and loading facilities are assumed adequate as they stand, with the delivery frequency increased to handle the increased production.

6.2.3.2 Impact on Sulphur Dioxide and Other Emissions

By roasting to 80% sulphur elimination in the fluid bed roasters, about 78% less SO_2 is emitted to the atmosphere from the smelter stack as compared with the existing process. At the 63 million lb per year production level, emissions would be 62 tonnes/day and at the 88 million lb level, 88 tonnes/day. Emissions of particulate matter are unlikely to change significantly from Program II.

The working environment in the converter aisle would be improved by having a greater amount of sulphur eliminated upstream in the fluid bed roasters.

6.2.3.3 Capital and Operating Costs

Capital costs of roaster and furnace modifications and acid plant construction are estimated to be $38 million and $46 million for the 63 million lb and 88 million lb annual production levels, respectively.

Operating costs for the roast/reduction smelting option are higher than for the existing process. Increased costs are significant due to greater reductant and electrical demands during smelting. Acid plant cost increases reflect higher production rates through two plants. Total increases are $5.3 million or $8.0 million, depending on production level.

6.2.3.4 By-Products of Emission Reduction

Increases in acid production with Program III are 371 tonnes/day and 522 tonnes/day at the 63 million lb and 88 million lb annual production rates.

6.2.3.5 Development, Engineering and Construction Time

About one and one half years are required to digest and appreciate the combined results of Inco's Thompson program and any pilot roast/reduction smelting project as it applies to the Falconbridge circumstance. Engineering and construction would take another one and one half years, totalling three years for the project.

6.2.4 Abatement Program IV: Conversion of Converter Gases to Acid

6.2.4.1 Modifications to Process Operations

Approximately 75% of the sulphur dioxide in the stack gas originates from the converters. Typically, at levels of production of 63 million lb and 88 million lb of nickel per year, the converter gas sulphur dioxide content of between 1.2% and 1.9% is too low to permit acid production without extremely high capital and operating costs for the acid plant. Therefore, recovery of acid directly from converter gases is only possible if the sulphur dioxide content can be increased or if blending with more highly concentrated streams is possible.

"Noranda" type hoods, for example, can be used to reduce air induction at the flue opening from about 400% to about 100% of the original converter off-gas volume. The resulting corresponding levels of sulphur dioxide in the acid plant feed gas (resulting from blending converter and roaster gases) has been estimated to vary between 5% and 7%.

Tight-hooding is more difficult to apply to nickel/copper type converters than to copper converters where blowing conditions are more steady and less metal splashing occurs.

Restricting the volume of air drawn from the area surrounding the converters affects air flow patterns in the region of the converter and permits the escape of converter gases into the workroom atmosphere. Therefore, a secondary emission collection system is also required in order to maintain acceptable safety and health conditions in the smelter.

No change in the current roasting practice is required. Electric furnace operation continues normally.

Converter aisle changes required are:

- Noranda type converter hooding capable of higher temperature operation to ensure reduced dilution by ingress air; secondary hooding to reduce fugitive emissions from the converter operations;
- gas cooling to permit use of mild steel, high velocity flue ducting downstream of the converters;

- dampers installed to isolate hoods over inactive converters and to redirect gas flows;
- electrostatic precipitators to clean the converter gases before blending with the roaster gases;
- a gas mixing chamber to ensure that the blended gases are homogenized.

For both levels of production considered, additional acid plant capacity is needed. At the 63 million lb and 88 million lb per year nickel production levels, the acid plants are sized at about 340 and 480 tonnes/day, 100% acid, respectively. The product is 95% acid.

6.2.4.2 Impact on Sulphur Dioxide and Other Emissions

Program IV reduces SO_2 emissions to levels of 104 tonnes/day and 143 tonnes/day for the two levels of nickel production considered.

The hooding of the converters should also result in some improvement in the working area environment. At the same time, the increased containment of particulate emissions at the converters would result in a reduction of emissions of fugitive particles by about 60%, while only marginally increasing the emissions from the acid plant.

6.2.4.3 Capital and Operating Costs

Total capital costs are estimated to be $47 million for the 63 million lb annual production level and $52 million at the higher level. In both cases, about $28 million is accounted for by the converter hooding.

Operating cost increases of $2.8 million and $3.3 million are primarily due to the greater production of sulphuric acid.

6.2.4.4 By-Products of Emission Reduction

Increases in the amount of acid manufactured are 307 tonnes/day and 434 tonnes/day at the 63 million lb and 88 million lb annual production rates.

6.2.4.5 Development, Engineering and Construction Time

There are four converters. The introduction of modified hooding would be undertaken incrementally. One hood would be designed, built and proven, with the others following. The full program, including smelter modifications and acid plant construction, would take about four years.

6.2.5 Abatement Program V: Regenerative Weak Gas Treatment

6.2.5.1 Modifications to Process Operations

This program involves essentially the same modifications as in Programs IA and IIA, but without any changes to the basic smelting process (i.e. no increased pyrrhotite rejection or increased roast). Without these changes, the amount of weak SO_2 off-gas is greater, which means that Program V requires a weak gas treatment plant larger than the other two programs.

In addition to the Flakt-Boliden gas treatment plant, smelter modifications required in this program are principally changes in the ducting from the converters and electric furnaces to reroute the gases to the treatment plant. Because of the present location of the electrostatic precipitator, this unit would have to be relocated or a new one would have to be installed.

A new contact section in the existing acid plant would be required to handle the total quantity of sulphur dioxide from the scrubbing plant and roasters.

6.2.5.2 Impact on Sulphur Dioxide and Other Emissions

With this abatement program, SO_2 emissions are reduced to levels of 33 tonnes/day and 48 tonnes/day for the 63 million lb and 88 million lb annual production levels.

No changes in the smelter working environment would occur.

6.2.5.3 Capital and Operating Costs

Capital costs for the modifications described in this section are $42 million and $48 million at the 63 million lb and 88 million lb annual production levels, respectively.

The corresponding operating cost increases are $12.4 and $14.0 million per year.

6.2.5.4 By-Products of Emission Reduction

The incremental acid production under Program V is 412 tonnes/day for the 63 million lb annual level and 578 tonnes/day for the 88 million lb annual level.

6.2.5.5 Development, Engineering and Construction Time

An initial development period of about 18 months may be required, after which the overall time required to design, procure and erect a weak gas treatment plant would be 18 months. Actual construction would begin about 24 weeks after the decision to start construction was taken.

6.2.6 Abatement Program VI: Non-Regenerative Treatment of Weak Gas Streams

6.2.6.1 Modifications to Process Operations

In this program, the Ammonia Double Alkali non-regenerative weak gas treatment removes the sulphur dioxide from the furnace and converter off-gases and then converts it into calcium sulphite and calcium sulphate (gypsum) which are relatively inert and can be disposed of as landfill.

This process is able to capture about 97% of the SO_2 passing through it; the remaining 3% goes to the smelter stack.

Smelter modifications would mainly involve rearranging the ductwork from the electric furnaces and converters and relocating the existing electrostatic precipitator (or constructing a new one). No changes in the existing acid plant are necessary.

For the scrubbing plant, a new Venturi scrubber-cooler would have to be added to clean the converter and furnace off-gases. An absorption tower with associated tanks, vessels, heat exchangers and pumps plus a neutralization plant including agitated mine tanks, thickener and vacuum drum filter, again with associated pumps, conveyors and vessels, would be required. An induced draft fan would be installed in the tail gas stream of the absorption tower.

6.2.6.2 Impact on Sulphur Dioxide and Other Emissions

With this abatement program, SO_2 emissions are reduced from 287 tonnes/day to 21 tonnes/day and from 406 tonnes/day to 27 tonnes/day at the 63 million lb and 88 million lb annual production levels, respectively.

No changes in the working environment around the electric furnaces and converter would occur with this program.

Because the weak gas streams are treated by wet scrubbing processes in both Programs V and VI, a reduction in particulate emissions by about 95% is expected to occur. There would be no effect on fugitive emissions.

6.2.6.3 Capital and Operating Costs

Total capital costs are $44 million and $47 million for the two levels of production. Incremental operating costs are approximately $11.3 million and $15.1 million.

6.2.6.4 By-Products of Emission Reduction

This abatement program differs from all the others in that its principal by-products are approximately 1,070 tonnes per day of calcium sulphite and calcium sulphate solids, not sulphuric acid. These solids are relatively inert waste products requiring disposal.

6.2.6.5 Development, Engineering and Construction Time

Overall time required to design, procure and erect the Ammonia Double-Alkali process plant is 18 months. Construction would begin about 24 weeks after the start of the project. As in the case of Abatement Program V, a period for development of the process, about 18 months, would be needed before a final decision is taken.

6.3 Conclusions

Of the programs examined, only roast/reduction and the collection of the existing weak gas streams will result in better than 50% reduction in emissions. Both pyrrhotite rejection (34%) and increased roasting (38%) must be combined with weak gas treatment to exceed 50% reduction; the former results in 91%, while the latter results in 89% reduction overall.

The "least cost" programs identified in Chapter 8 are, with one exception only, major process changes. The exception is a combination of pyrrhotite rejection with weak gas treatment, which would also result in the minimum emission level of 36 tonnes of SO_2 per day. Installation of weak gas treatment can be added to the system at any convenient time; the two segments of the program need not be installed simultaneously.

Pyrrhotite rejection requires the shortest implementation time of all the least cost options, requiring about one and one half years for a production rate of 88 million lb of nickel per year. It could be instituted almost immediately at the lower production rate. With weak gas treatment added, a further two to three years construction work would be needed.

Roast/reduction smelting, at the other extreme, would require at least three years construction time but would probably not be completed and fully operational until 1990 or 1991.

FIGURE 6.1

SCHEMATIC OF FALCONBRIDGE ABATEMENT PROGRAM I

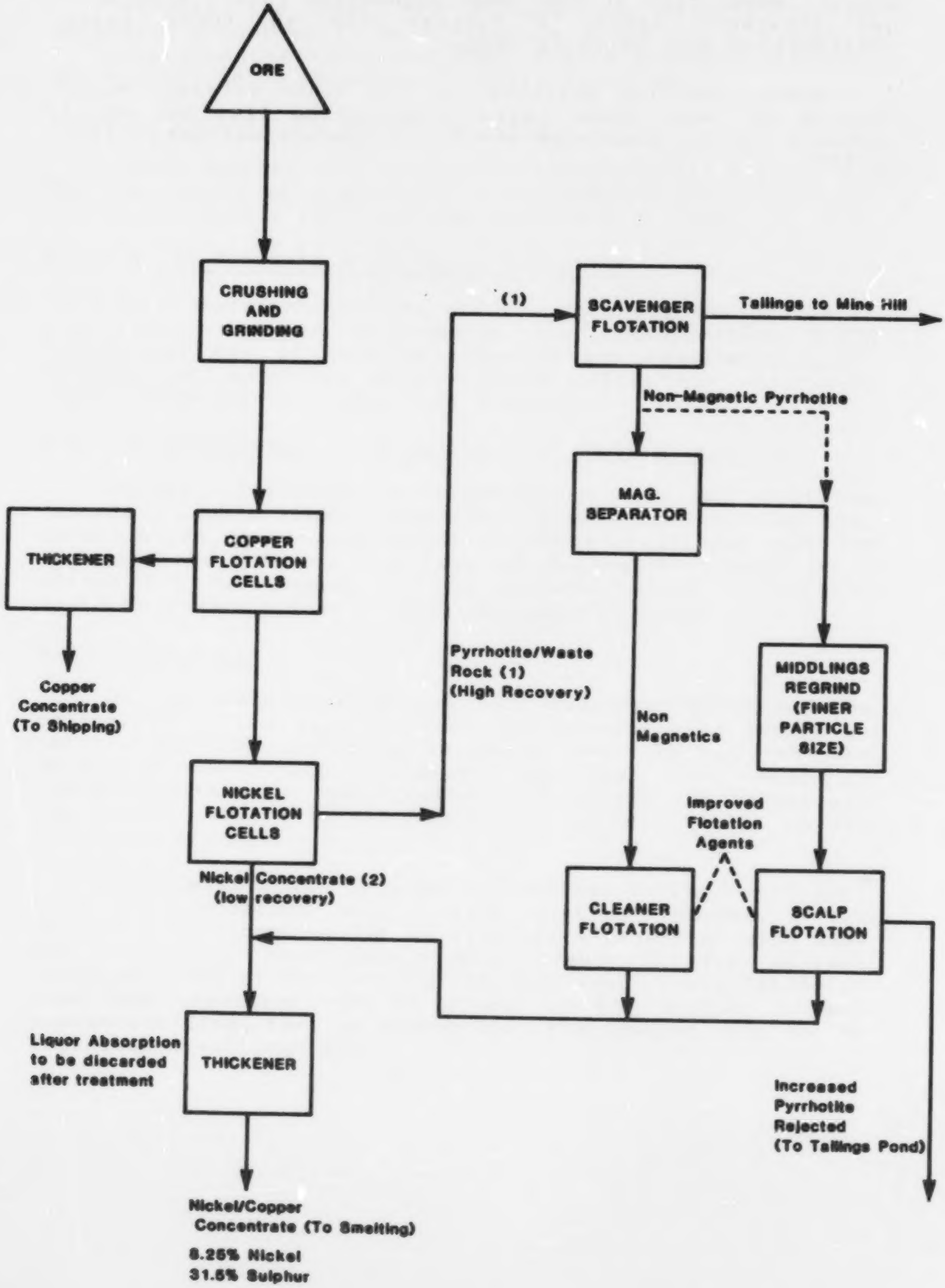

ORE
CRUSHING AND GRINDING
(1)
SCAVENGER FLOTATION
Tailings to Mine Hill
Non-Magnetic Pyrrhotite
MAG. SEPARATOR
THICKENER
COPPER FLOTATION CELLS
Copper Concentrate (To Shipping)
Pyrrhotite/Waste Rock (1) (High Recovery)
MIDDLINGS REGRIND (FINER PARTICLE SIZE)
Non Magnetics
NICKEL FLOTATION CELLS
Improved Flotation Agents
Nickel Concentrate (2) (low recovery)
CLEANER FLOTATION
SCALP FLOTATION
Liquor Absorption to be discarded after treatment
THICKENER
Increased Pyrrhotite Rejected (To Tailings Pond)
Nickel/Copper Concentrate (To Smelting)
8.25% Nickel
31.5% Sulphur

FIGURE 6.2

SCHEMATIC OF FALCONBRIDGE ABATEMENT PROGRAM IA

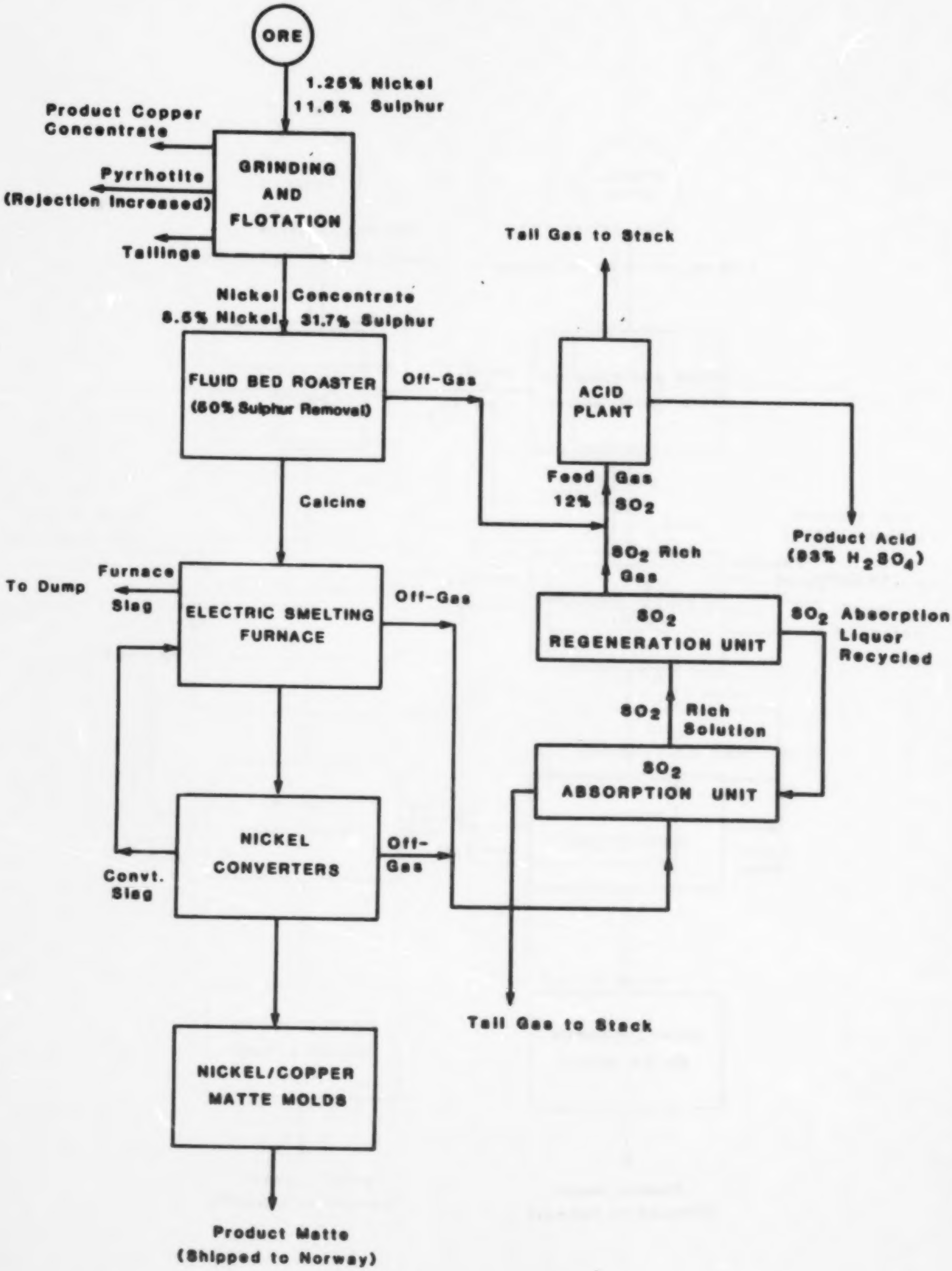

ORE
1.25% Nickel
11.6% Sulphur
Product Copper Concentrate
Pyrrhotite (Rejection Increased)
Tailings
GRINDING AND FLOTATION
Nickel Concentrate
8.5% Nickel, 31.7% Sulphur
FLUID BED ROASTER (50% Sulphur Removal)
Off-Gas
Calcine
Tail Gas to Stack
ACID PLANT
Feed Gas
12% SO2
Product Acid (93% H2SO4)
SO2 Rich Gas
SO2 REGENERATION UNIT
SO2 Absorption Liquor Recycled
SO2 Rich Solution
SO2 ABSORPTION UNIT
To Dump
Furnace Slag
ELECTRIC SMELTING FURNACE
Off-Gas
NICKEL CONVERTERS
Off-Gas
Convt. Slag
Tail Gas to Stack
NICKEL/COPPER MATTE MOLDS
Product Matte (Shipped to Norway)

FIGURE 6.3

SCHEMATIC OF FALCONBRIDGE ABATEMENT PROGRAM II

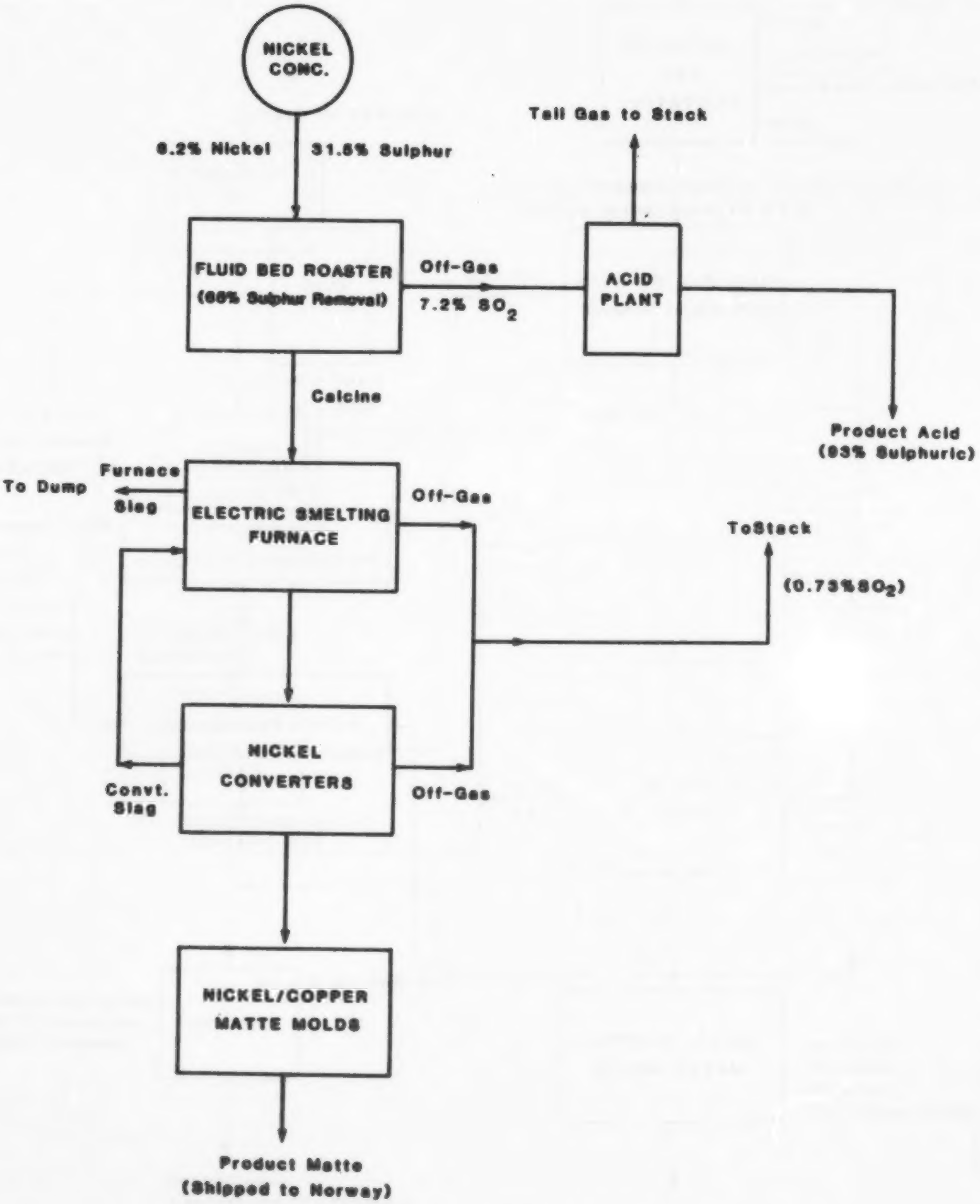

NICKEL CONC.
6.2% Nickel
31.5% Sulphur
FLUID BED ROASTER
(66% Sulphur Removal)
Off-Gas
7.2% SO_2
ACID PLANT
Tail Gas to Stack
Product Acid
(93% Sulphuric)
Calcine
Furnace Slag
To Dump
ELECTRIC SMELTING FURNACE
Off-Gas
ToStack
(0.73%SO_2)
NICKEL CONVERTERS
Convt. Slag
Off-Gas
NICKEL/COPPER MATTE MOLDS
Product Matte
(Shipped to Norway)

FIGURE 6.4

SCHEMATIC OF FALCONBRIDGE ABATEMENT PROGRAM IIA

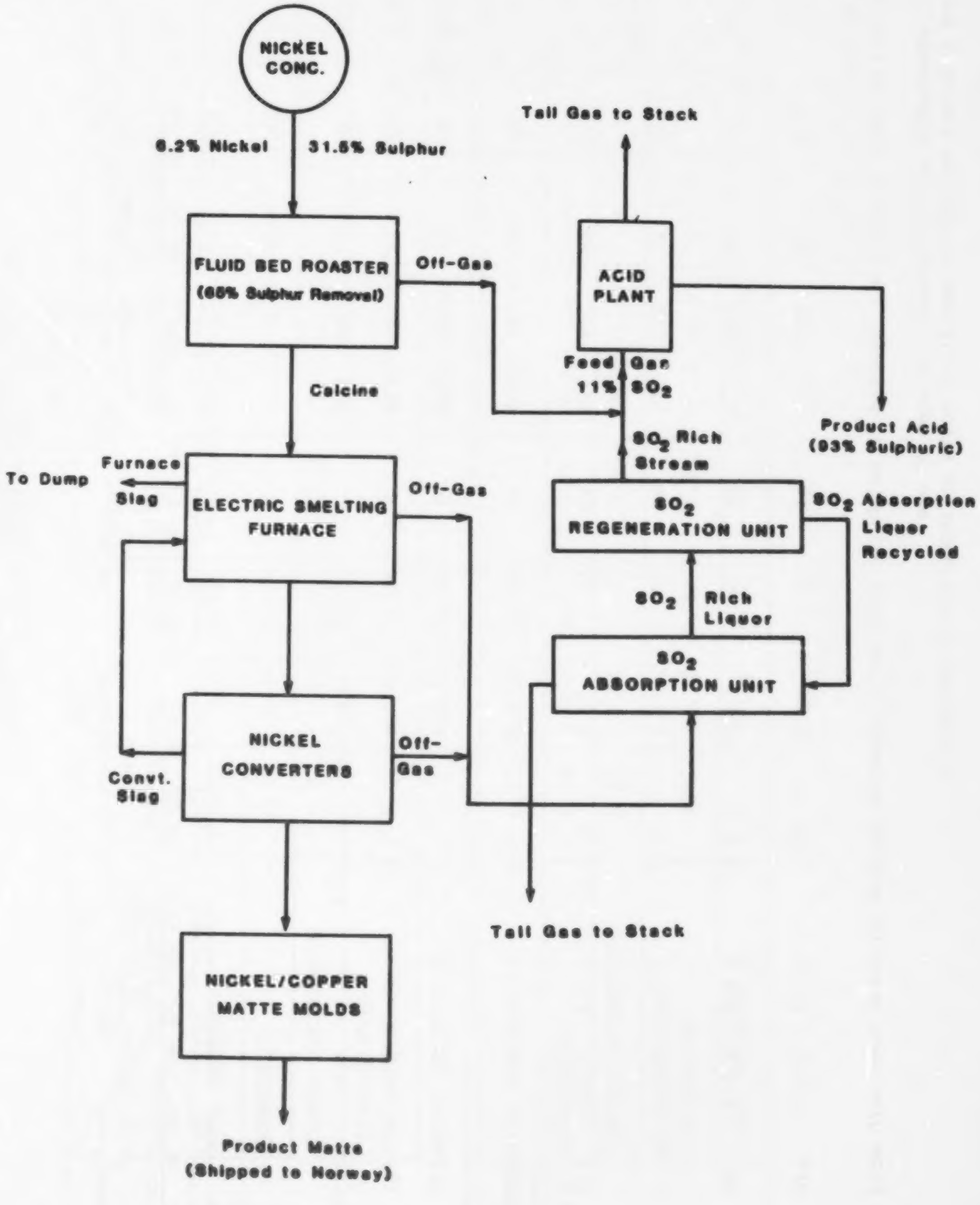

NICKEL CONC.
6.2% Nickel
31.5% Sulphur
FLUID BED ROASTER
(65% Sulphur Removal)
Off-Gas
Calcine
Tail Gas to Stack
ACID PLANT
Product Acid
(93% Sulphuric)
Feed Gas
11% SO_2
SO_2 Rich Stream
To Dump
Furnace Slag
ELECTRIC SMELTING FURNACE
Off-Gas
SO_2 REGENERATION UNIT
SO_2 Absorption Liquor Recycled
SO_2 Rich Liquor
SO_2 ABSORPTION UNIT
NICKEL CONVERTERS
Off-Gas
Convt. Slag
Tail Gas to Stack
NICKEL/COPPER MATTE MOLDS
Product Matte
(Shipped to Norway)

TABLE 6.1

ABATEMENT PROGRAM SUMMARY - FALCONBRIDGE

	ABATEMENT PROGRAM	SO_2 Emissions (tonnes/day)[1]		Reduction in SO_2 from Base Case (tonnes/day)		Capital Cost ($ millions)		Additional Operating Costs ($million/yr)		Development, Engineering and Construction Time (years)		By-Products Acid[2] (tonnes/day)	
		63 MM lb/yr	88 MM lb/yr	63 MM lb/yr	88 MM lb/yr	63 MM lb/yr	88 MM lb/yr	63 MM lb/yr	88 MM lb/yr	63 MM lb/yr	88 MM lb/yr	63 MM lb/yr	88 MM lb/yr
	Base Case - Existing Process	287	406	-	-	-	-	-	-	-	-	-	-
I	Pyrrhotite Rejection (1)	189	267	98	139	0[3]	3.5[3]	-2.8[3,4]	-4.2[3,4]	-	1.5	-177[4]	-249[4]
II	Increased Roasting (2)	178	252	109	154	4.5	22	0.4	1.2	1.25	2.5	182	254
III	Roast/Reduction Smelting (3)	62	88	225	318	38	46	5.3	8.0	3.	3.	371	522
IV	Conversion of Converter Gases to Acid (4)	104	143	183	263	47	52	2.8	3.3	4.	4.	307	434
V	Regenerative Weak Gas Treatment (5)	33	48	239	358	42	48	12.4	14.0	1.5-3	1.5-3	412	578
VI	Non-Regenerative Weak Gas Treatment (6)	21	27	260	379	44	47	11.3	15.1	1.5	1.5	-	-
IA	Pyrrhotite Rejection Plus Weak Gas Treatment (1A)	25	36	262	370	28[3]	35[3]	6.0[3]	9.0[3]	1.5-3	1.5-3	88	124
IIA	Increased Roasting Plus Weak Gas Treatment (2A)	32	44	255	362	43	62	10.6	14.4	1.5-3	2.5-3	418	591

[1] Annual emissions divided by 365.

[2] As 93% acid not including current acid production. By-product sulphuric acid would generate revenue to break even with acid disposal cost.

[3] Not including mining costs associated with increased tonnages of ore.

[4] Figures with negative signs indicate savings in operating costs or reduction in production.

TABLE 6.2

EFFECT OF PYRRHOTITE REJECTION ON METAL VALUES

	NICKEL PRODUCTION 10^6 lb/yr / PRODUCT	NICKEL			COPPER			COBALT			SULPHUR		
		ASSAY %	10^6 lb/year		ASSAY %	10^6 lb/year		ASSAY %	10^6 lb/year		ASSAY %	10^6 lb/year	
		-	63	88	-	63	88	-	63	88	-	63	88
PRESENT PROCESS	MILL TAILINGS	0.09	3.35	4.68	0.05	1.86	2.61	-	-	-	0.85	31.60	44.30
	PYRRHOTITE	0.66	8.44	11.80	0.10	1.28	1.79	-	-	-	26.40	337.00	472.00
	COPPER CONCENTRATE	0.84	0.22	0.31	29.91	7.90	11.20	-	-	-	33.23	8.77	12.40
	NICKEL/COPPER CONCENTRATE	6.24	64.70	90.50	4.78	49.50	69.30	0.25	2.59	3.62	31.47	329.00	456.00
	METAL RECOVERY %	-	84.50	84.50	-	94.60	94.60	-	86.00	86.00	-	-	-
INCREASED PYRRHOTITE REJECTION	MILL TAILINGS	0.10	3.96	5.54	0.05	1.98	2.77	-	-	-	0.85	33.70	47.10
	PYRRHOTITE	0.76	12.90	18.10	0.16	2.72	3.81	-	-	-	27.50	468.00	654.00
	COPPER CONCENTRATE	0.84	0.24	0.33	29.91	8.55	11.80	-	-	-	33.20	9.50	13.20
	NICKEL/COPPER CONCENTRATE	8.50	64.70	90.30	6.74	51.30	71.60	0.34	2.59	3.62	31.20	238.00	332.00
	METAL RECOVERY %	-	79.50	79.50	-	92.60	92.60	-	81.00	81.00	-	-	-

7. THE OUTLOOK OF WORLD MARKETS AND THEIR IMPLICATIONS FOR INCO AND FALCONBRIDGE

Abstract

Nickel is a world metal commodity. Demand for nickel is derived from the demand for the products which use nickel. These products include various types of steel and other alloys, which in turn are used to manufacture products such as aircraft, motor vehicles, chemical and electrical goods. Nickel demand is dependent primarily on capital (investment) spending and to a lesser extent on consumer spending.

Nickel has become a mature commodity in that consumption no longer exhibits strong growth trends. Markets are essentially static, but demand is cyclical, resulting in swings from strong to weak demand, which produce wide fluctuations in the sales, revenues and profits of nickel producers.

Annual compound growth rates of nickel consumption in the Western World averaged about 6% throughout the postwar years to the early 1970's. This growth rate slowed to just over 1% per year during the period 1974 to 1979 and it is projected to stabilize at between 1.1% and 1.7% per year throughout the forecast period 1983 to 1996. This would bring total consumption from the 1970 level of 570,000 tonnes to a peak of about 670,000 tonnes in the 1990 to 1996 period. These forecasts are predicated on the basis of slow but steady recovery of the economy during the 1980's.

Installed nickel production capacity in the Western World currently exceeds consumption by about 50% with projected peak demand not exceeding installed capacity throughout the forecast period. Few producers are expected to operate at capacity. Nickel prices, which rose in real terms throughout the 1970's, have declined recently from their 1981 level because of low demand. Nickel prices are expected to recover and are forecast to remain close to the 1981 level or even to decline slightly in real terms throughout the forecast period. The result is a cost-price squeeze on many producers, which may force closures of some production facilities. These reductions in capacity are unlikely to reduce supply sufficiently to produce significant upward pressure on prices.

The market share of Canadian-mined nickel has steadily declined in recent years to a current level of less than 25% of the Western World consumption. It is anticipated that Canadian-mined nickel will capture about a 30% share of the Western World market throughout the forecast period.

The demand for copper and other by-product metals is similarly projected to exhibit low growth over the forecast period. Prices for most of these metals, from a 1981 base, are forecast to remain steady or even to decline slightly.

Sulphuric acid and gypsum are the two main by-products of the proposed abatement technologies. Sulphuric acid is marketable, both in Canada and the United States. It is anticipated that there is sufficient demand for acid up to an additional 1.2 million tonnes by 1995 to produce revenues to the Companies even after transportation costs are deducted from the price. Gypsum, however, would require further processing for subsequent use in wallboard. Specific markets for smelter produced gypsum were not examined for this report.

It must be emphasized, however, that forecasting is an inexact science and its associated uncertainties are further compounded in the midst of the current unstable economic period. Nonetheless, forecasts can aid in understanding the potential market situations, which the Companies are likely to face in the future, and their effects on the financial health of the firms.

The corresponding effect of the forecasted nickel demand, supply and prices on Inco and Falconbridge is also examined. Both Companies have recently experienced adverse financial performance, due in part to a poor nickel market, as well as to difficulties experienced with poor foreign investments. With the present outlook for nickel, growth in revenues and profits will be limited. As a result, the Companies will have to pay particular attention to their costs, given no real increase in world nickel prices. In the context of the uncertain economic outlook, as a minimum, both Companies will have to make further aggressive efforts in order to control costs as well as exercise innovative management and operating practices in order to remain in viable financial shape for the balance of the decade.

7.1 Historical Perspective: Nickel Production, Consumption and Prices

7.1.1 Nickel Production

Nickel is mined in 25 countries throughout the world, but Western World output has traditionally been dominated by Canada and France (New Caledonia).

Both these producers have held their prominent positions for many years. Production began in New Caledonia in 1875, but, by 1905, Canada had taken over the position as the world's leading nickel producer. By 1970, Canada accounted for 42% of total world mine production and for 54% of Western World production. While this dominance persisted throughout the early 1970's, it has been eroded by the addition of new production facilities in many countries as shown in Table 7.1.

Nickel only occurs in economic amounts in two basic ore types - sulphide and laterite. Each ore type is distinct and requires different processing techniques. This distinction is an important factor in the economics of processing. Laterite ores cannot be concentrated by conventional means and the processing of these low-grade ores is energy intensive and therefore costly. On the other hand, sulphide ores can be concentrated and the sulphur in the ore may contribute energy to the smelting process. In addition, these deposits frequently contain copper, iron and precious metals which are recovered as co-products.

Canadian output is based on sulphide ores, while that of New Caledonia is based on laterite ores. During the last decade, the market dominance of sulphide ores has decreased as new facilities have been developed, particularly in the early 1970's, based primarily on lateritic ore bodies. The development of new laterite ores has slowed considerably, particularly as energy prices have risen.

Total Western World nickel refining capacity is approximately 800,000 tonnes, as shown in Table 7.1.

Actual Western World production of nickel was 550,000 tonnes in 1980, compared to total design capacity of 768,000 tonnes. Effective capacity is less than design capacity since some production facilities would require several years, coupled with large expenditures, to reach their rated capacity.

7.1.2 Nickel Consumption

Given its utilization in the capital goods sector, nickel consumption is concentrated in industrialized Western World countries. The United States is the single largest consumer of refined nickel. In 1980, it accounted for 28% of Western World nickel consumption, followed closely by Japan with 23% of the world share. Collectively, the countries of Western Europe account for 39% of total consumption.

Since the early 1950's, nickel demand has fluctuated in cycles typically running five to seven years. Variations in demand from year to year are highly dependent upon the level of economic activity. Nickel demand is particularly related to capital goods spending since 65% of nickel is consumed in that sector, with only 35% in consumer durables.

From 1950 to the early 1970's, a long period of exceptionally rapid economic growth caused the annual growth rate in nickel consumption to average between 5% and 6%. High rates of demand growth were attributed to three main factors:

- other Western World nations attaining higher standards of living during the postwar recovery period;
- growth in defence spending;
- rapid expansion of capital goods' industries throughout the Western World.

In 1975, several decades of strong growth in nickel consumption ended. Associated mine production was also curtailed as shown in Figure 7.1.

In economic terms, nickel is an intermediate product since it is used to make other final products. The intermediate markets for nickel include stainless and heat resistant steels, alloy steels, super and other alloys and electroplating metals. In turn, these are used to make a wide variety of products including aircraft, motor vehicles, chemicals, electrical and fabricated metal goods.

Canada consumes about 5% of its nickel production, i.e. about 10,000 to 12,000 tonnes per year. Major consuming industries are stainless steel, coinage electroplating and iron and steel foundry.

Uses for nickel have changed little over the last decade. Nickel scrap, however, is recycled and has been a significant source of nickel supply. In fact, nickel consumption can be correlated with production only by taking into account the large quantities of stainless steel scrap that are recycled.

Substitutes are available for many of nickel's uses, although alternate materials often require some sacrifice in performance or increased costs and substitution to date has had only a small impact on nickel demand.

7.1.3 Nickel Prices

Until the 1970's, Inco Limited, the world's largest producer of nickel, was the price leader in the nickel industry. Inco Limited could maintain prices by restricting production. As a result, nickel prices remained stable at U.S. $0.34 per pound until 1947. Thereafter, steady increases in prices were recorded which enabled producers to mine low-grade ore and to exploit nickel laterites profitably. From the mid-1950's until 1969, nickel prices increased essentially at the same rate as inflation. The frequent price fluctuations common to other non-ferrous metals, such as copper, were absent.

During the 1960's and 1970's, technological changes plus the entry of a number of laterite nickel producers into the industry resulted in a significant erosion of Inco Limited's market share. Many laterite nickel producers had comparatively inflexible production targets because their projects were located in countries which were dependent on a regular inflow of hard currency. Also, since many laterite producers are government subsidized, they continued to produce at levels close to capacity during the slump in nickel demand in the mid to late 1970's.

As a result, although list prices for nickel continued to record increases throughout the 1970's, as shown in Table 7.2, spot prices, which more accurately reflect immediate supply and demand conditions, displayed substantial instability in the latter half of the decade, reflecting the more realistic competitive supply situation and a slackening in demand.

7.2 Forecasts of Demand, Supply and Prices of Nickel: 1982-1996

7.2.1 Future Demand for Nickel

Forecasting the demand for nickel is based on certain assumptions about the demand for various products in which nickel is used, since use (demand) of nickel has historically been linked to rates of industrial growth.

Even under the most stable economic conditions, forecasting is an inexact science. Its uncertainty is further compounded under unstable economic conditions, such as exist at present. Consequently, the "most probable" prediction of nickel demand should be considered only as an indicator.

The projected growth in industrial production is based on a "most probable" scenario, assuming a modest revival of industrial activity in the world's major economies and the gradual containment of inflation. Although such predictions may be inaccurate, they serve as a means to estimate market conditions and hence, as a means to examine the implications for Inco and Falconbridge.

Based on its use in intermediate and final products, correlated to projections of industrial growth in the major consuming countries of the United States, Japan and Western Europe, projected annual growth rates for nickel in the Western World under the most likely scenario are given below:

Forecast Period	Annual Growth Rates	Peak Consumption
1980-1985	1.7%	577,800 tonnes
1986-1990	1.4%	620,800 tonnes
1991-1996	1.2%	669,100 tonnes

The rate of growth in demand for nickel in the Western World over the forecast period to 1996 will be sluggish. Specific production efficiencies and substitution efforts will lead to reduced requirements for nickel in the production of superalloys, alloy steel and electroplating. Specific assumptions have been made for each of the major submarkets for the three forecast periods.

If economic recovery for the period 1980 to 1985 is slower than forecast, then the assumed 1.7% annual growth rate in nickel consumption will be overly optimistic.

For the period 1986 to 1990, due to declines in both the use of superalloys and the use of nickel in the automotive industry and due to the stabilization of nickel use in alloy steels, the primary stimulus to demand is assumed to be the production of commercial and defence aircraft. For the 1990 to 1996 period, nickel consumption is assumed to move with overall industrial production.

For Japan, the assumptions suggest increased nickel consumption in the automotive and pollution control sectors during 1980 to 1985. By 1985, these sectors are assumed to be mature and consumption is assumed to move with overall industrial production to the end of the forecast period.

In Western Europe, conditions are somewhat different. Nickel use in the automotive market is generally assumed to be stable. Potential growth markets are represented by nuclear power development and pollution control.

These forecasts for nickel demand are predicated on the basis of overall industrial activity for the forecast period to 1996. The level of industrial activity in the Western World is, in turn, based on assumptions about rates of exchange, interest rates, money supply and gross national product. Tables 7.3 and 7.4 show the specific rates and/or indexes used for each year of the forecast period. In general, they indicate a general containment of inflation and slow overall economic recovery.

On the basis of these assumptions for final nickel demand and overall economic performance, forecasts of demand were made for the U.S., Japan and Europe. The aggregate was factored to account for the rest of the Western World, while the centrally planned economies[1] were assumed to be self-sufficient. The most likely forecast of nickel demand by country for particular years is shown in Table 7.5.

All country groups show increases in demand over 1980 levels, although growth rates vary. Nickel consumption in the U.S. and Europe is expected to stabilize and Japan is likely to emerge as the single largest consumer of nickel during the 1990's.

---

[1] These include: the U.S.S.R., Cuba, People's Republic of China, Poland, Albania, Czechoslovakia and the German Democratic Republic.

The U.S.S.R. and Cuba are also net exporters of nickel, although their exports to western countries fluctuate with market conditions and their need for foreign exchange. As such, their influence on the world nickel market is unpredictable.

7.2.2 Nickel Supply: 1980-1996

Current Western World refining capacity for nickel is approximately 768,000 tonnes, well in excess of 1980 levels of demand for 530,000 tonnes. With relatively weak growth in demand, peak consumption is expected to be around 670,000 tonnes in the mid-1990's, still well below capacity.

In addition to Western World production, nickel exports can be expected from centrally planned economies. The volume of nickel imported from the Soviet Union and Cuba depends to some extent on market conditions. (Imports rose during Inco's strike in 1978-1979.) In 1980, Western countries imported a total of approximately 35,000 tonnes from the U.S.S.R. and Cuba, 70% of which went to Western European markets. Since 1975, nickel imported from centrally planned economies has accounted for between 4% to 8% of Western World consumption and this market share is assumed to persist and perhaps increase. This increase could jeopardize Canadian sales in Europe and, to a lesser extent, in Japan. The view is held by some that this share will rise significantly, in which case, the existing oversupply situation will simply be worsened. The Soviet Union appears to be increasingly supportive of a policy to increase raw material exports in order to generate the foreign exchange necessary for food and high technology imports, so nickel exports can be expected to continue.

Price will obviously play a role in determining the level of U.S.S.R. exports (although state control allows for more flexibility in establishing levels of production regardless of world prices), but it was assumed that these exports would not exceed 10% of Western World consumption.

Potential production capacity is compared with projected demand in Table 7.6 (assuming 6% of consumption requirements are imported from the centrally planned economies). If all existing operations remain in production, a significant excess capacity situation will prevail throughout the entire forecast period.

As a result of overcapacity and declining real nickel prices (see Section 7.2.3), both Inco and Falconbridge have cut back their foreign operations. If these conditions persist, either some if not all producers will be forced to operate below capacity or some existing nickel producers will be forced out of the market in the coming years.

The lack of detailed cost information on individual operations makes it difficult to assess the vulnerability of specific operations. However, work done in recent years suggests that, in 1975, some producing countries were experiencing a cost-price squeeze. Since 1975, it can be assumed that surging energy costs, escalating interest rates and rising labour costs have further increased cost pressures. The laterite-based operations in New Caledonia and in the Philippines require four to five times the energy inputs for processing than comparable sulphide-based operations. Similarly, rising interest costs can only have served to increase pressures on newer operations, given the capital expenditures involved. The Marinduque operation in the Philippines is known to be strongly affected by the costs of carrying its investment. Even the more established producers, which have been forced into increased debt loads under weak market conditions in recent years, are adversely affected by interest costs.

Other operations are also heavily influenced by political-economic concerns. The Philippine government has assumed the majority interest in the Marinduque operation to avoid the firm's bankruptcy. The facility is considered to be at risk, but it is difficult to determine the extent to which the government will go to sustain operations.

The French government is also an important force in the New Caledonia operations. Particularly under the current French administration, it is assumed that the nickel industry in New Caledonia will be supported, given the importance of nickel production to the local economy. Botswana, another high cost producer in which the government owns a large share, relies heavily on nickel exports for foreign exchange.

In conclusion, this growth forecast, along with the current overcapacity situation, indicates that sufficient capacity will be available to last the world into the 1990's. Much of the capacity is in government owned or controlled hands and these producers cannot be expected to operate solely by the same criteria as private sector corporations. The burden could therefore fall mainly on private sector corporations, including Canadian firms, to cut production during oversupply conditions. This possibility suggests that unless conditions, potentially including corporate strategies, change significantly, Canada will not likely be able to return to the same production rates in the 1980's that it had in the early 1970's.

The overcapacity situation will tend to put downward pressure on prices. However, if nickel prices remain significantly below those necessary to cover operating costs (as is the present case), some producers will be forced to close their operations. Hanna Mining in the U.S.

and Exmibal in Guatemala are closed now due to depressed prices and other candidates for closure, if low prices persist, include: Marinduque in the Philippines, Empress Nickel Mining in Zimbabwe, Greenvale in Australia and BCL in Botswana. Falconbridge Dominicana is reopening but it will likely be forced to close or to operate intermittently if weak market conditions prevail.

Therefore, the most likely scenario is that of continued idle capacity overhanging the nickel market, with some producers operating at near capacity due to political influences; many producers, especially in the private sector, operating well below capacity; and a few producers closing down. Producer costs together with the mild economic growth will continue to exert upward pressure on prices while the overhanging idle capacity will exert a moderating influence on price increases. The North American producers will continue to bear the brunt of the reduced production levels which will likely result in decreased nickel mining operations in Sudbury for the foreseeable future as compared to the past.

7.2.3 The Price of Nickel

Nickel demand is forecast to be sluggish and supply is expected to exceed demand throughout the period to 1996. Nickel prices are determined by supply-demand relationships, not by the costs of production. The result is that real nickel prices are forecast to recover to 1980 levels and remain flat or even decline during the period. In other words, prices will increase at about the same rate or slightly below the rate of inflation.

Although low prices often serve to stimulate demand, this traditional relationship between demand and price is breaking down in current markets, as nickel has become a mature commodity with limited new applications in the short term.

Real nickel prices have declined since 1981 and are not forecast to recover until 1983-1984. The real price of nickel is therefore expected to average $3.00 per pound in 1981 U.S. dollars throughout the forecast period. Data available to the Task Force indicate that both Inco and Falconbridge production costs are under $3.00 (U.S.)[2] per pound, although Inco has a significantly larger cost advantage.

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[2] Falconbridge 1980 Form 10-K Submission;
Inco 1980 Form 10-K Submission;
Sheppards and Chase, February 1982, Nickel Analysis;
Walwyn Stodgell, September 1, 1981, Inco Limited Analysis.

7.3 Allocation of Market Share

To determine the range of potential market share for Canadian nickel, given demand forecasts, import patterns were assessed for the period 1977 to 1981. For Canadian refined nickel, total finished nickel imports from Canada were compared to total finished nickel consumption in Europe, Japan and the United States.

To determine Western World market share for all nickel mined in Canada, finished exports to these countries from Norway (Falconbridge refinery) and the U.K. (Inco refinery) were also considered. A market share range for each of the major markets was then constructed, as shown in Table 7.7.

The magnitude of these ranges points out some of the difficulties in pinning down market share. While it could be argued that a longer historical period should be considered, new operations have come on stream in the last decade (e.g. Indonesia and the Philippines), altering the distribution of market share. Similarly, in looking ahead, the ongoing cost-price squeeze will, in all likelihood, force existing facilities out of production, again altering market share. The political-economic factors noted in the preceding section compound the difficulties already inherent in attempting to assess market shares.

For the purposes of this report, the midpoint of each range is advanced as a reasonable estimate of future Western World market share. These estimates have been used to project future demand for Canadian produced nickel as shown in Table 7.8. (Tables 7.9 and 7.10 illustrate the allocation of forecasted demand and realized prices for the Sudbury operations of Inco and Falconbridge over the period 1980 to 1996.)

7.4 Copper and By-Product Metals

Several other metals are produced at the Inco and Falconbridge operations as by-products of nickel processing. These include copper, cobalt, gold, the platinum group and other metals. The demand, supply and price prospects for each are discussed in subsequent Sections.

7.4.1. Copper

Demand for copper to the Western World is expected to grow at a moderate rate over the forecast period. Annual growth rates of 2.2% are predicted to the mid-1980's, declining to 1.5% for the balance of the decade and to 1.3% in subsequent years. Therefore, for all Western World demand, the level will be 8.5 million tonnes by 1996.

Copper supply is expected to decline by 1% per year from 1980 levels until 1985, with growth picking up at 2% per annum thereafter. This will bring total North American supply of copper to 1.8 million tonnes by 1996, 25% below peak production of 2.4 million tonnes in 1973.

Similar to nickel, copper prices are expected to be relatively flat in real terms over the forecast period. By 1996, real prices are expected to remain virtually unchanged from the 1981 level of U.S. $0.79 per pound, although there will be cyclical variations over the years.

7.4.2 Cobalt

Growth in demand for cobalt is forecast by the U.S. Bureau of Mines to be 2.9% per year to 1990 and 2.7% per year to 2000. These forecasts would appear to be optimistic given political-economic factors; growth rates of about 2% would be both more conservative and more likely.

About 90% of world cobalt production is a by-product of copper production, largely in Zaire and Zambia, and hence, growth of cobalt supply can be expected to move with growth of copper supply in these countries. There are few mine projects around the world with the potential to produce significantly new quantities of cobalt, except in the U.S. New capacity could only be justified by high prices.

In October 1982, merchant prices were as low as U.S. $3.50 per pound down from a high of $45 per pound in 1980 and are subject to considerable uncertainty.

7.4.3 Platinum

Growth rates of platinum consumption are anticipated to fall significantly below the level of 9.4% per annum experienced during 1969 to 1979, to around 2% per annum.

The U.S.S.R. and South Africa are major suppliers of platinum and export requirements are likely to drive their production rates. However, more than half the world platinum production is a by-product of nickel and copper production and supply is therefore influenced by the price of these metals. Falling real prices for nickel and copper can be expected to curtail supply, although these contractions may be more than offset by U.S.S.R. and South African production, in addition to greater scrap recovery.

World platinum markets are therefore likely to face slowing demand and increasing supply throughout the forecast period. With this imbalance, real prices are likely to decline in the period 1982 to 1986 to a range of U.S. $250 to $300 per troy ounce and may, after some supply adjustments, pick up to a range of U.S. $300 to $400 per ounce after 1986.

7.4.4 Other Metals

Demand for gold is expected to grow at a rate of about 1.4% per year over the forecast period, given its use in jewellery, industrial applications and market speculation. Expansion of supply is expected primarily due to gold's importance to the foreign exchange earnings of several countries where development of mine capacity and production of gold is less responsive to price than other metals. Gold prices are projected to continue their normal volatile cyclical swings but in a downward path from a peak of U.S. $669 (1981) per ounce to a range of U.S. $350 to $450 (real) by 1996.

Silver consumption in the forecast period will be influenced by the same economic conditions. A 2.3% annual growth rate is forecast. About 10% to 15% of world silver supply is a co-product of nickel and copper production. Thus, market trends in these sectors will have only a small influence on supply. More importantly, however, silver is a by-product of other base metals (lead, zinc) and its supply will therefore be more influenced by demand for these base metals.

Silver supply is estimated to increase by 7.5% in the mid-1980's, with no major increases thereafter. Prices are then forecast to decline to (1981) U.S. $6 to $7 per ounce until 1986 and to firm to (1981) U.S. $10 to $15 over the period 1987-1996.

Selenium demand is forecast to grow at 3.7% per annum to 1990 and 3.2% thereafter, given increased recycling, substitution and mature industrial markets for vehicles and xerographic equipment. Selenium is almost entirely a by-product of copper refining, hence, supply from this source will decline, but is likely to be offset by increased scrap recovery. Prices are expected to range from (1981) U.S. $10 to $15 per pound.

Tellurium is also a by-product of copper refining and is used in metal fabricating and organic chemicals manufacturing. Aggregate demand for tellurium is forecast to be 1.1% per annum throughout the forecast period. Supplies, which are dependent on copper production, are forecast to be tight in the mid-1980's, which will bring world prices to the level of (1981) U.S. $15 to $20 per troy ounce by 1986 and to $12 to $15 during 1987 to 1996.

7.5 Sulphuric Acid: Market and Price Outlook

In North America, sulphuric acid demand has been increasing at a rate of 3.5% to 4% per year. In 1980, sulphuric acid demand in eastern Canada amounted to about 1.8 million tonnes. It is expected to grow at a moderate pace to about 1.9 million tonnes by 1990.

In North America, 60% of the sulphuric acid produced is used for phosphate fertilizer; the remainder is used by petroleum refining, metal mining, rubber, explosives, pulp and paper and water treatment industries.

The market is divided into two segments - merchant and captive. Captive users are large consumers of acid and they generally enter into long-term contracts for acid supplies. Merchant users consume less acid, thereby often paying a higher price per tonne.

Given the limited supplement in the growth in acid consumption in Canada, smelter-produced acid will have to turn to American markets. The primary market for smelter acid from Sudbury would be located in the U.S. Great Lakes states. Here, acid consumption is expected to decline from the 1980 level of 2.0 million tonnes to 1.7 million tonnes by 1990. The secondary market would be located in the northeastern United States and in the New England States where a modest decline from 2.1 to 2.0 million tonnes is projected. The largest market would be the southeastern United States and the Gulf states where acid is used to make fertilizers and other chemical products. Currently, this market consumes 24 million tonnes and its consumption is forecast to grow to 36 million tonnes by 1990.

The home market and the primary and secondary U.S. markets will constitute the prime market areas for Canadian smelter acid. Transportation and terminalling costs make the tertiary market (U.S. southeast) uneconomical. While net back prices in Sudbury vary for each of the markets, the conclusion of the market analysis is that there is sufficient demand for additional sulphuric acid in northeastern North America. The problem with smelter-produced acid is that its volume depends directly on nickel production levels which may be cyclical due to market conditions, enhancing the difficulty to capture and maintain markets.

Thus, the supply and demand situation in the sulphuric acid market is considered to be relatively volatile. Nevertheless, it is believed that the maximum volumes of acid which could potentially be produced by the Sudbury smelters could be marketed for at least a breakeven price, i.e., net of transportation and terminalling costs averaged across all markets. Thus, positive revenues are potentially possible from the sale of acid. However, for the purposes of this analysis, a $0 net back price is used as a conservative estimate.

7.6 Implications of Forecasts for Inco and Falconbridge

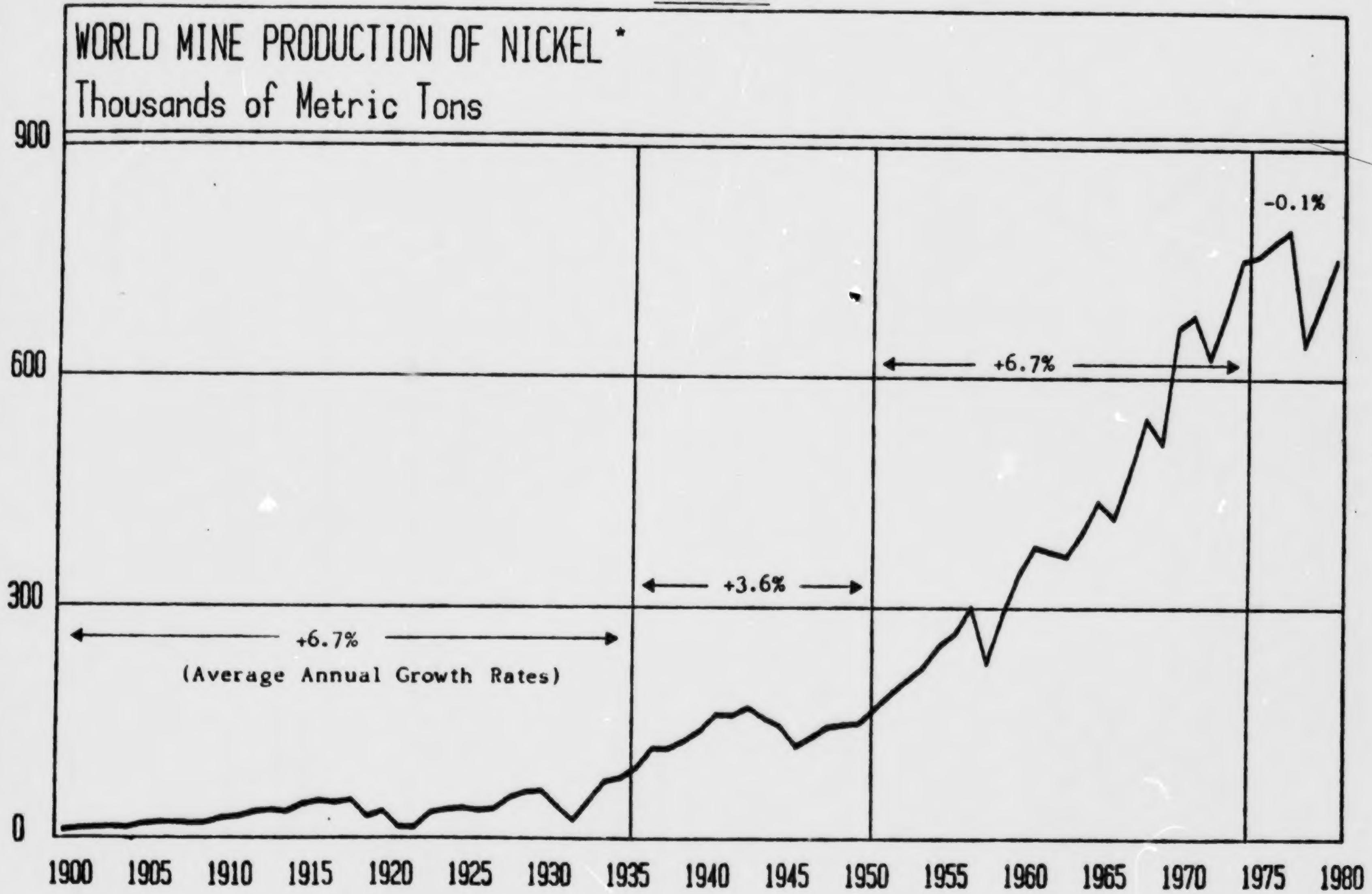
The predictions of nickel demand and supply present a less than optimistic picture. The world nickel market is forecast to be soft for the balance of the century. Coupled with the overcapacity situation, this is likely to result in a shakeout of some producers. Those with high costs would be likely candidates, although other economic and political goals may keep some of the least efficient producers in the market. As a result, this places strong adverse pressures on market producers such as Inco and Falconbridge.

Inco enjoyed a position of price leadership throughout most of this century and its spread between costs and prices yielded good returns. Falconbridge, while not as low a cost producer, nonetheless enjoyed healthy revenues and profits on nickel sales.

With the entry of more producers and a significant overcapacity situation which will persist throughout the forecast period, real prices are likely to remain stable or even to decline from the 1981 base level. As a result, the Companies will have to pay particular attention to cost-price relationships. Given the forecasts of inflation, rising wage, fuel and other costs, the real costs of producing nickel and other metals will increase.

In the short term, possible reductions in inventory, research and development, exploration and perhaps some overhead costs can be expected to reduce the rate of increase in costs. Over the longer term, continued gains in productivity, fuel savings and efficiencies due to modernization will be required. With prudent financial and operational management, the Companies can therefore be expected to weather the current adverse conditions in the nickel market and emerge in healthier positions once demand picks up. Healthier revenues and profits will require an extended length of time and aggressive pursuit of these measures. The fundamental changes which have taken place in the nickel market mean that these two Companies are unlikely to experience the robust earnings they did in the years up to 1975. Nonetheless, they appear to have the capability to adapt to market changes and to continue as viable corporate enterprises for the balance of the century.

FIGURE 7.3



* Metal content.

Source: Metallgesellschaft, 1900-1979; World Bureau of Metal Statistics, 1980.

TABLE 7.1

DESIGN CAPACITY OF EXISTING MINING AND REFINING[1] OPERATIONS: WESTERN WORLD
(000's of tonnes of contained nickel)

	Mining	Refining
Canada	298	196
Guatemala[2]	13	-
Indonesia	66	5
Australia	87	54
New Caledonia	125	50
Philippines	45	34
Botswana	18	-
Zimbabwe	20	17
South Africa	25	22
United States	10	41
Finland	6	13
Greece	27	27
Yugoslavia	34	34
Brazil	9	9
Colombia	20	20
Dominican Republic	30	30
U.K.	-	51
Norway	-	39
Japan	-	101
France	-	25
	833	768

1. Finished products only.
2. Mothballed.

Sources: An Anatomy of the Nickel Industry and its Future. World Bank, September 1979: Towards a Nickel Policy for the Province of Ontario. Ministry of Natural Resources: Mineral Bulletin MP157. Nickel: Energy, Mines and Resources Canada. 1978. "Nickel Resource Analyses", B. Baldessari, Mining Magazine January. 1982.

TABLE 7.2

AVERAGE ANNUAL NICKEL PRICES[1]

1970-1980

(U.S. Dollars Per Pound)

	Current Dollars	Constant 1980 Dollars
1970	1.29	2.50
1971	1.33	2.46
1972	1.40	2.48
1973	1.53	2.57
1974	1.74	2.69
1975	2.07	2.92
1976	2.25	3.02
1977	2.36	2.99
1978	2.09	2.47
1979	2.71	2.95
1980	3.42	3.42
Average Annual Rate of Change 1970 - 1980 (Per Cent)	10.2	3.2

1. A major producer price for nickel cathodes in New York.

Deflated by the United States Gross National Product Implicit Price Index, 1980=100.

Source: Metals Week.

TABLE 7.3

SELECTED ECONOMIC INDICATORS
HISTORICAL DATA

	1976	1977	1978	1979	1980	1981
NORTH AMERICAN INTEREST RATES, PER CENT (Weighted Sum of Long-term Government Bonds)						
	7.9931	7.76	8.56	9.41	11.49	13.87
CANADIAN DOLLAR IN U.S. FUNDS (Average Noon Spot Rate, in U.S. Cents)						
	101.41	94.03	87.70	85.36	85.54	83.40
IMPLICIT PRICE INDEX, UNITED STATES (1.972=100)						
	132.1	139.8	150.0	162.8	177.4	193.7
Per Cent Change	-	5.8	7.3	8.5	9.0	9.2
IMPLICIT PRICE INDEX, CANADA (1971=100)						
	160.2	171.5	182.4	201.3	222.7	245.0
Per Cent Change	-	7.1	6.4	10.4	10.6	10.0
BUSINESS GROSS FIXED CAPITAL FORMATION, CANADA IMPLICIT PRICE INDEX (1971=100)						
	163.9	177.6	192.3	211.4	230.3	256.0
Per Cent Change	-	8.4	8.3	9.9	8.9	11.2
WAGES AND SALARIES PER EMPLOYED PERSON, CANADA (Dollars)						
	11,385	12,333	13,021	13,993	15,239	16,899
Per Cent Change	-	8.3	5.6	7.5	8.9	10.9

TABLE 7.3 (continued)

SELECTED ECONOMIC INDICATORS
HISTORICAL DATA

	1976	1977	1978	1979	1980	1981
CONSUMER PRICE INDEX, ENERGY, CANADA (1971=100)						
	169.2	189.8	207.4	227.8	264.2	343.6
Per Cent Change	-	12.2	9.3	9.8	16.0	30.1
GROSS NATIONAL EXPENDITURE, CANADA (Constant 1971 Millions of Dollars)						
	119,249	121,762	121,281	130,115	130,160	134,070
Per Cent Change	-	2.1	3.7	3.0	0.0	3.0
GROSS PROVINCIAL EXPENDITURE, ONTARIO (Constant 1971 Millions of Dollars)						
	47,465	48,373	49,660	50,689	50,175	59,179 f
Per Cent Change	-	1.9	2.7	2.1	(1.0)	2.0

() indicates decline

f forecast

Source: Statistics Canada.

TABLE 7.4

SELECTED ECONOMIC INDICATORS
FORECAST

	1982	1983	1984	1985	1986	1987	1988	1989	1990*
NORTH AMERICAN INTEREST RATES, PER CENT									
	14.25	12.75	12.75	13.25	12.00	10.50	11.50	11.50	11.50
CANADIAN DOLLAR IN U.S. FUNDS	79.5	76.5	78.5	78.5	79.5	80.5	83.5	85.5	87.5
IMPLICIT PRICE INDEX, UNITED STATES (1972=100)									
	206.6	221.1	234.4	248.5	263.4	279.2	295.9	313.7	332.5
Per Cent Change	6.7	7.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
IMPLICIT PRICE INDEX, CANADA (1971=100)									
Overall	271.2	297.0	321.9	347.7	376.2	404.4	434.7	467.4	502.4
Per Cent Change	10.7	9.5	8.4	8.0	8.2	7.5	7.5	7.5	7.5
BUSINESS GROSS FIXED CAPITAL FORMATION, CANADA IMPLICIT PRICE INDEX (1971=100)									
Capital	282.2	306.8	332.4	359.0	387.4	417.0	446.2	477.4	510.8
Per Cent Change	10.2	8.7	8.3	8.0	7.9	7.6	7.0	7.0	7.0
WAGES AND SALARIES PER EMPLOYED PERSON, CANADA (Dollars)									
Labour	18,927	21,028	23,257	25,466	27,758	30,200	32,616	35,225	38,043
Per Cent Change	12.0	11.1	10.6	9.5	9.0	8.8	8.0	8.0	8.0

* Cdn Dollar assumed to be 91.3¢ in U.S. Funds 1991 and beyond.

TABLE 7.4 (continued)

SELECTED ECONOMIC INDICATORS
FORECAST

	1982	1983	1984	1985	1986	1987	1988	1989	1990
CONSUMER PRICE INDEX, ENERGY, CANADA (1971=100)									
Energy	417.8	506.8	554.9	604.9	660.6	716.7	777.7	843.8	915.5
Per Cent Change	21.6	21.3	9.5	9.0	9.2	8.5	8.5	8.5	8.5
GROSS NATIONAL EXPENDITURE, CANADA (Constant 1971 Millions of Dollars)									
	132,730	135,385	140,258	144,044	144,000	148,032	151,733	155,526	159,414
Per Cent Change	(1.0)	2.0	3.6	2.7	(0.0)	2.8	2.5	2.5	2.5
GROSS PROVINCIAL EXPENDITURE ONTARIO (Constant 1971 Millions of Dollars)									
	50,411	51,419	53,219	54,496	54,233	55,199	56,358	57,542	58,750
Per Cent Change	(1.5)	2.0	3.5	2.4	(0.5)	1.8	2.1	2.1	2.1

() indicates decline

Source: The Economics Practice, Currie, Coopers & Lybrand.

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TABLE 7.5

DERIVED DEMAND FORECASTS FOR NICKEL: SCENARIO
(000's of tonnes)

	1980*	1985	1990	1996
United States	148.2	158.6	163.3	171.9
Japan	122.0	142.2	161.0	180.2
Western Europe	208.5	219.3	234.6	250.4
Other Countries	51.5	57.7	61.9	66.7
Western World	530.2	577.8	620.8	669.2

*Actual

Source: World Bureau of Metal Statistics.
Forecasts by Singer Associates.

TABLE 7.6

PROJECTED WESTERN WORLD PRODUCTION CAPACITY[1] OF AND DEMAND FOR NICKEL

(000's of tonnes)

	1985	1990	1996
Production Capacity	767[2]	770[3]	773[4]
Demand	530	578	670
Surplus	237	192	103

Notes:

1. Assumes Hanna and Guatemala remain closed; Dominican Republic operates intermittently.

2. Assumes imports of 39,000 tonnes; (from centrally planned economies).

3. Assumes imports of 42,000 tonnes.

4. Assumes imports of 45,000 tonnes.

TABLE 7.7

WESTERN WORLD MARKET SHARE RANGES FOR CANADIAN NICKEL: 1977-1981

(%)

	North America	Europe	Japan	Other
Canadian refined	40-60	11-13	3-6	25
Canadian mined (refined in Canada, Norway or Wales)	45-75	20-35	4-8	35

Source: Derived by Singer Associates from World Bureau of Metal Statistics Data.

TABLE 7.8

PROJECTED DEMAND FOR CANADIAN PRODUCED NICKEL BY MARKET

(000's of tonnes)

	1985	1990	1996
Refined in Canada			
North America	91	101	113
Asia	6	7	7
Europe	27	28	31
Other	7	8	9
TOTAL	131	144	160
Mined in Canada			
(Refined in Canada, Norway, or the U.K.)			
North America	110	121	136
Asia	8	9	9
Europe	59	63	68
Other	9	11	12
TOTAL	186	204	225

Source: Singer Associates.

TABLE 7.9

FORECAST OF DEMAND: INCO AND FALCONBRIDGE

	DEMAND FOR CANADIAN MINED NICKEL (000 000 of lbs)	DEMAND FOR INCO NICKEL (000 000 of lbs)		DEMAND FOR FALCONBRIDGE NICKEL (000 000 of lbs)
		TOTAL	SUDBURY	
1980	429.7	344.0	261.4	66.5
1981	426.3	341.3	259.4	66.0
1982	423.0	338.6	225.4	65.5
1983	419.7	336.0	225.4	65.0
1984	416.4	333.4	253.4	64.4
1985	413.1	330.7	251.3	63.9
1986	420.6	336.7	255.9	65.1
1987	428.3	342.9	260.6	66.3
1988	436.1	349.1	265.3	67.5
1989	444.1	355.5	270.2	68.7
1990	452.2	362.0	275.1	70.0
1991	459.9	368.2	279.8	71.2
1992	467.7	374.4	284.5	72.4
1993	475.6	380.7	289.3	73.6
1994	483.7	387.2	294.3	74.9
1995	491.9	393.8	299.3	76.1
1996	500.2	400.4	304.3	77.4

TABLE 7.10

FORECAST OF REALIZED PRICES[1] NICKEL AND COPPER

(CURRENT $)

	INCO AND FALCONBRIDGE REALIZED PRICES FOR NICKEL (U.S. $/lb)	FALCONBRIDGE REALIZED PRICE FOR COPPER (U.S. ¢/lb)	INCO REALIZED PRICE FOR COPPER (U.S. ¢/lb)
1979	2.31 (Falconbridge); 2.43 (Inco)	90	91
1980	3.25 (Falconbridge); 3.14 (Inco)	99	100
1981	3.09 (Falconbridge); 2.99 (Inco)	79	82
1982	2.92	74	75
1983	3.27	81	82
1984	3.45	91	92
1985	3.64	98	99
1986	3.81	106	107
1987	4.04	115	116
1988	4.30	122	124
1989	4.55	127	129
1990	4.78	133	134
1991	4.98	140	141
1992	5.20	147	148
1993	5.42	157	158
1994	5.73	165	167
1995	6.02	172	173
1996	6.27	179	180

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[1] The price forecast begins in 1982 and that price is not reflective of the current situation

8. ABATEMENT PROGRAMS FROM A FINANCIAL PERSPECTIVE

Abstract

Some emission abatement options require large capital expenditures on new plants and equipment. In some cases, operating cost savings in the future act to offset the initial capital outlay and may eventually provide a return on the committed capital.

Prior to making an investment decision, a company would conduct in-depth analyses of risk, overall profitability, ability to finance and impacts on other operations. This Task Force did not have sufficient information or resources to conduct such an in-depth analysis. However, the Task Force has examined the magnitude of the costs of the various abatement programs.

The potential effects of taxes, leverage and revenues from acid, among others, could alter the financial attractiveness of these programs, but these effects have not been examined here.

Where several options might achieve a given level of abatement, the Task Force selected for further study those that appear to be cost effective. The economic viability of each cost effective option was tested using internal rate of return as the main criterion.

For Inco, roast/reduction smelting (RRS) is the only option which can be justified solely on economic grounds. For Falconbridge, only one option, increased pyrrhotite rejection, appears to be economically viable.

The effects of the eight least cost abatement programs on production costs (cents per pound of nickel) and unit abatement cost (dollars per tonne of SO_2 removed) were estimated. The incremental costs of the programs for Inco range from 2.2 cents to 20.2 cents per pound of nickel. Cost per tonne of SO_2 removed varies from $18 to $81.

For Falconbridge, the incremental production costs of the five least cost abatement programs range from a savings of 4.2 cents per pound to a cost of 14.7 cents per pound. The cost per tonne of SO_2 removed ranges from a savings of $72 to a cost of $159.

8.1 Introduction

Inco and Falconbridge can achieve various levels of SO_2 abatement by more than one method. Each firm would prefer the method that appears to offer the largest contribution to profits over time or, in the absence of projected profits, the method that appears to cost the least to install and maintain.

In Section 8.2, various technically sound primary and secondary abatement programs for each firm are examined and those which yield the highest profit contribution or lowest cost for each successive abatement level under consideration (i.e. the most cost effective program) are selected.

In Section 8.3, the economic viability of the various programs selected are examined. A program may be considered economically viable if it promises to yield a sufficiently large return on invested capital to compensate the providers of that capital (i.e. the firm, private investors and the banks) for the technical and economic risks of an industrial investment and for the uncertainty of making accurate projections of cash flows far into the future. For the purposes of this section, nominal percentage returns (i.e. including inflation) were calculated on nominal (i.e. inflated) cash flows.

Section 8.4 profiles the abatement programs in terms of unit abatement costs and incremental production costs. An annualized pre-tax cost is calculated for each option. This set of values is used to estimate both the cost per tonne of SO_2 abated and the additional production cost per pound of nickel associated with each abatement program.

Forecasts of prices, inflation and other economic factors were drawn from Chapter 7 in this report. Estimates of cost increases and cost savings associated with individual abatement programs were taken from Chapters 4 and 6.

8.2 Cost Effective Abatement Programs

Fifty-four abatement programs which might be applied to the Sudbury operations of Inco Limited and eight abatement programs which might be applied to those of Falconbridge Limited were identified. To reduce this relatively large number of programs to a more workable level, a criterion of cost effectiveness was applied. A cost effective program was defined as one which yields the highest profit contribution or lowest overall cost for a given abatement level. The measure of a program's contribution to profit or overall cost used in this exercise is the net present value (NPV) of its estimated cash flow stream.

Each program has a cost stream associated with it. Each stream includes the capital outlay for plant and equipment and the expected operating and maintenance costs which may continue indefinitely once the equipment begins to function. Operating and maintenance costs associated with a given option may be offset by cost savings achieved through the use of more efficient equipment. Components of each cashflow stream (Appendices 8.1 and 8.2) were escalated using inflation forecasts discussed in Chapter 7. The stream of estimated future cash flows obtained in this way forms the basis for the economic evaluation of each program.

It is difficult to compare directly the cash flow streams associated with different programs without recognizing the time value of money. This concept argues that one dollar today is worth more in its ability to command goods and services than one dollar one year from today. The value of the future dollar is, in fact, discounted. By discounting each future cash inflow or outflow by an appropriate discount rate, the cash flow stream may be reduced to a single value, the cumulative net present value or NPV.

The selection of an appropriate discount rate is highly subjective. A nominal discount rate of 16.5% (i.e. including inflation of 6.5%) was used. This rate lies between the current rate of inflation (i.e. about 11%) and the rate which currently might be applied to a relatively high risk capital investment in the private sector (i.e. about 25%).

The Task Force selected for further analysis that program which, for a given level of emission reduction, had the highest NPV.

8.2.1 Inco

By applying the cost effective criterion, the number of programs for Inco's Sudbury operations was reduced from fifty-four to eight. These programs are displayed in Table 8.1. Cumulative net present values reported in Table 8.1 include each program's estimated capital cost.

8.2.2 Falconbridge

The number of cost effective programs which might be applied to Falconbridge's Sudbury operations were reduced from eight to five. These are displayed in Table 8.2.

Of the cost effective programs for Falconbridge, only increased pyrrhotite rejection results in savings and yields a NPV of $37.4 million (Cdn). All the others impose costs on the Company because each involves a stream of net cash outflows.

Pyrrhotite rejection would reduce the volume of the concentrate currently being processed which would result in lowering the recovery (production) costs of nickel and its by-products. These costs may be offset further by increased mining costs. (See Chapter 6).

8.3 Economic Viability of Abatement Programs

In the simplest terms, a program may be considered economically viable if it pays back over time more than the capital cost of its program with due regard to the time value of money. Cumulative net present value, discussed in Section 8.2 is one such measure of a program's viability. However, it suffers from the disadvantage that it is calculated using an arbitrarily selected discount rate. This disadvantage may be overcome by calculating an internal rate of return.

The internal rate of return is that discount rate which, when applied to a cash flow stream, would yield a net present value of zero. It is analogous to the annual interest rate applied to a savings deposit or to a guaranteed investment certificate and its use allows the identification of programs which utilize committed capital more efficiently.

The internal rate of return is a very sensitive indicator of a program's economic viability. Where a cash flow stream consists almost entirely of cash outflows, the internal rate of return rapidly approaches an infinitely large negative percentage. Where a stream consists almost entirely of cash inflows, the internal rate of return rapidly approaches an infinitely large positive percentage. To rank a program near these extremes, a less sensitive measure such as the net present value may be employed. Tax effects and leverage (i.e. financing a portion of a capital investment by borrowing) can usually improve a firm's return on its portion of a capital investment, particularly under a scenario of steadily increasing or consistently high inflation. The potential effects of these two additional variables were not assessed in this test of a program's ability to stand alone.

Internal rates of return were estimated for the cost effective programs. A firm with unlimited funds would invest in mutually exclusive programs in order of descending rates of return above some threshold value. A nominal return of 16.5% per annum was selected as the threshold value which a firm might choose.

8.3.1 Inco

Estimated internal rates of return are displayed in Table 8.3. In a no-risk environment, any program which offers a positive return would be considered economically viable. In a more risky environment, nominal returns in excess of 16.5% per annum might be considered economically viable.

Based on the estimated internal rates of return in the present risky environment, the roast/reduction smelting (RRS) abatement program appears to be economically viable. However, had the costs for all programs been estimated as comprehensively as those of the Inco alternative, the rates of return displayed in Table 8.3 for all other programs might be lower. Indeed, the internal rates of return for roast/reduction smelting could approach that of the Inco alternative.

Prospects of a much higher sustained nickel price on world markets might encourage the firm to lower its threshold criteria for project acceptance and, under these circumstances, the firm might find several of the programs worth considering. Unfortunately, higher real nickel prices are not expected within the next two decades.

8.3.2 Falconbridge

Internal rates of return could not be calculated on the Falconbridge options because each cash flow stream consists almost entirely of cash outflows or cash savings. Consequently in Table 8.2, net present values are calculated by discounting the cash stream at the threshold rate of 16.5% as a test of economic viability.

The only economically viable program for Falconbridge appears to be increased pyrrhotite rejection. Adoption of this program would force Falconbridge to forego some future acid sales. None of the other programs can be considered economically viable in the long run.

8.4 Annualized Cost Methods

This method permits the abatement programs for Inco and Falconbridge to be viewed from two perspectives:

- the anticipated impact on production costs in cents per pound;

- the cost in dollars per tonne of SO_2 removed.

The annualized cost was calculated as follows:

- The annual cost of amortizing the inflated capital investment over a twenty-year period was calculated at an arbitrarily selected discount rate of 10%. This step is analogous to calculating the annual payment, including interest, which would be required on a twenty-year mortgage. The result was expressed in 1982 dollars.

- Estimates of annual operating and maintenance costs (or cost savings) in 1982 dollars were added to (or subtracted from) the annualized capital cost.

Data for calculating the annualized costs were drawn from Chapters 4 and 6. For reasons previously discussed, the Task Force acknowledges that these estimates are not comprehensive but are useful for purposes of comparison.

Annualized costs were all calculated on a pre-tax basis.

8.4.1 Inco

Annualized costs have been used to calculate the cost per unit of abatement and the incremental nickel production costs. The results are summarized in Table 8.4.

The incremental cost per lb of nickel produced for the Inco abatement programs ranges from 2.2 cents to 20.2 cents. The cost per tonne of SO_2 removed ranges from $18 to $81. The Inco alternative would increase the cost per lb of nickel produced by 7.5 cents and affect SO_2 removal at a cost of $72.20 per tonne. By comparison, the roast/reduction smelting program would increase the cost of production by 2.2 cents at a cost per tonne of SO_2 removal of $18.40. The unit costs shown in Table 8.4 assume that the firm will operate at an annual production level of 280 million pounds of nickel for at least the next 20 years.

8.4.2 Falconbridge

Results are summarized in Table 8.5. The incremental cost per lb of nickel produced for Falconbridge abatement programs ranges from an expected decrease of 4.2 cents per lb to an increase of 14.7 cents per lb.

With respect to the expected decrease in production cost by pyrrhotite rejection, the related cost per tonne of SO_2 removed is an implied reduction of $72 per tonne of SO_2 removed for an annual emission level of 267 tonnes of SO_2 per day. The remaining abatement programs result in an increase in cost per tonne of SO_2 removed from $64 to $159. The latter achieves an emission level of 36 tonnes of SO_2 per day.

8.5 Conclusions

For various emission reduction levels, an abatement program has been identified as technically feasible and cost effective for both Companies. Based on the cost effective programs outlined, emission levels of 1,045 to 43 tonnes per day for Inco and 267 to 36 tonnes per day for Falconbridge are possible.

Based on the preceding analysis, only two abatement programs (RRS at Inco and increased pyrrhotite rejection at Falconbridge) satisfied the Task Force criterion for economic viability. Higher real nickel prices would encourage the firms to lower the threshold criterion by which they judge the economic viability of major programs.

TABLE 8.1

INCO COST EFFECTIVE ABATEMENT PROGRAMS[1]

PROGRAM	EMISSION REDUCTIONS[2] (tonnes/day of SO_2)	CAPITAL COST ($/millions)[3]	NET PRESENT VALUE[4] ($/millions)[3]
RRS	913	264.4	17.9
RRS + IORP	1,086	305.4	-54.5
RRS + RWGT + IORP	1,182	373.0	-119.1
CCM + RRS	1,523	339.4	-116.5
CCM + RRS + IORP	1,696	380.0	-188.4
CCM + RRS + RWGT + IORP	1,802	380.4	-252.6
CCM + RWGT + RRS + IORP	1,831	448.5	-282.8
(CCM + RRS) + RWGT + IORP	1,927	524.0	-343.5
IRRA (Inco alternative)	1,064	430.0	-104.6

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[1] Based on 54 technically feasible abatement programs described in Chapter 4 (Appendix 4.1), eight programs were identified as least cost. The Inco alternative (IRRA) is provided for comparison purposes and details of the difference in cost estimation are outlined in Chapter 4 (Appendix 4.2).

[2] Assuming an annual nickel production level of 280 million lb.

[3] 1982 Canadian dollars.

[4] Cumulative net present value at a discount rate of 16.5% for a planning horizon to the year 2015.

TABLE 8.2

FALCONBRIDGE COST EFFECTIVE ABATEMENT PROGRAMS[1]

PROGRAM	EMISSION REDUCTIONS[1] (tonnes/day SO_2)	CAPITAL COST ($/millions)[2]	NET PRESENT VALUE[3] ($/millions)[2]
Pyrrhotite Rejection	139	3.5	37.4
Increased Roast	154	22.0	-29.9
Direct Conversion to Acid	263	52.0	-73.7
Roast/Reduction Smelting	318	46.0	-78.0
Pyrrhotite Rejection Plus Weak Gas Treatment.	370	35.0	-114.0

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[1] Assuming an annual nickel production level of 88 million lb.

[2] 1982 Canadian dollars.

[3] Cumulative net present value at a discount rate of 16.5% for the planning horizon to the year 2020.

TABLE 8.3

INTERNAL RATE OF RETURN INCO ABATEMENT PROGRAMS

PROGRAM	INTERNAL RATE OF RETURN (%) ON CAPITAL INVESTMENT AT PLANNING HORIZON[1] INTERNAL FINANCING
RRS	18.0%
RRS + IORP	13.5%
RRS + RWGT + IORP	9.8%
CCM + RRS	11.6%
CCM + RRS + IORP	8.4%
CCM + RRS + RWGT + IORP	5.1%
CCM + RWGT + RRS + IORP	4.4%
(CCM + RRS) + RWGT + IORP	0.5%
IRRA (Inco Alternative)	14.4%

[1] Planning horizon is year 2015.

TABLE 8.4

SUMMARY OF FINANCIAL REVIEW OF INCO ABATEMENT PROGRAMS[1]

PROGRAMS	EMISSION REDUCTIONS[2]	ANNUALIZED COST	INCREASED COST PER TONNE SO_2 REMOVED	INCREASED PRODUCTION COST PER LB NICKEL
	tonnes/day	\$/millions[3]	\$ per tonne[3]	cents[3]
RRS	913	6.1	18.40	2.2
RRS + IORP	1086	16.4	41.40	5.9
RRS + RWGT + IORP	1182	28.7	66.50	10.2
CCM + RRS	1523	20.3	36.50	7.2
CCM + RRS + IORP	1696	30.6	49.90	10.9
CCM + RRS + RWGT + IORP	1802	42.8	65.00	15.3
CCM + RWGT + RRS + IORP	1831	44.4	66.00	15.9
(CCM + RRS) + RWGT + IORP	1927	56.7	81.00	20.2
IRRA	1064	25.6	72.20	7.5

[1] Based on 54 technically feasible abatement programs, eight were identified as cost effective. The Inco alternative is provided for comparison.

[2] Annual production level of 280 million lbs of nickel.

[3] 1982 Canadian dollars.

TABLE 8.5

SUMMARY OF FINANCIAL REVIEW OF FALCONBRIDGE ABATEMENT PROGRAMS[1]

PROGRAMS	EMISSION REDUCTIONS[2]	ANNUALIZED COST	INCREASED COST PER TONNE SO_2 REMOVED	INCREASED PRODUCTION COST PER LB NICKEL
	tonnes/day	$/millions[4]	$ per tonne[4]	cents[4]
Pyrrhotite Rejection	139	-3.6 [3]	-72.00	-4.2
Increased Roast	154	3.5	64.00	4.1
Direct Conversion to Acid	263	9.1	94.00	10.3
Roast/Reduction Smelting	318	12.6	111.00	14.4
Pyrrhotite Rejection Plus Weak Gas Treatment	370	12.8	159.00	14.7

[1] Eight abatement programs were identified as technically feasible; five were identified as cost effective.

[2] Annual production level of 88 million lbs of nickel.

[3] Reduction in costs.

[4] 1981 Canadian dollars.

APPENDIX 8.1

SUMMARY OF CAPITAL AND OPERATING COST ASSUMPTIONS FOR INCO ABATEMENT PROGRAMS

Copper Circuit Modification

- installed and operational by 1986
- construction during 1984, 1985, 1986
- $75 m. (1982)[1] - $22.5, $30, $22.5
- increased operating cost of $5.35 m.
- increased acid production of 345.7 tonnes (000's) per annum

RWGT on Copper Circuit Modification (alone)

- installed and operational by 1991
- construction during 1989, 1990, 1991
- $75 m. (1982)[1] - $22.698, $30.264, $22.698
- increased operating cost of $4.975 m.
- increased acid production of 69.9 tonnes (000's) per annum

NRWGT on CCM (alone)

- installed and operational by 1991
- construction during 1989, 1990, 1991
- $68.4 m. (1982)[1] - $20.52, $27.63, $20.52.
- increased operating cost of $5.7 m.
- no increase in acid production

Roast/Reduction Smelting

- installed and operational by 1991
- construction during 1987, 1988, 1989, 1990, 1991
- $264.4 m. (1982)[1] - $26.44, $52.88, $79.52, $66.1, $39.66
- operating cost savings of $24.9 m. (annual) (Appendix 8.3)
- increased acid production of 542.4 tonnes (000's) per annum

RWGT on RRS

- installed and operational by 1994
- construction during 1992, 1993, 1994
- $68.1 m. (1982)[1] - $20.43, $27.24, $20.43
- operating cost increase of $4.266 m.
- increased acid production of 122.6 tonnes (000's) per annum

NRWGT on RRS

- installed and operational by 1994
- construction during 1992, 1993, 1994
- $56.8 m. (1982)[1] - $17.04, $22.72, $17.04
- increased operating cost of $4.6 m.
- no increase in acid production

[1] All costs are given in 1982 Canadian dollars.

APPENDIX 8.1 (continued)

Outokumpu Flash Furnace

- installed and operational by 1988
- construction during 1986, 1987, 1988
- $271 m. (1982)[1] - $81.3, $108.4, $81.3
- operating cost savings of $21.50 m. (Appendix 8.3)
- increased acid production of 498.0 tonnes (000's) per annum

RWGT on OFF (alone)

- installed and operational by 1991
- construction during 1989, 1990, 1991
- $69.0 m. (1982)[1] - $20.7, $27.6, $20.7
- increased operating cost of $4.383 m.
- increased acid production of 79.3 tonnes (000's) per annum

NRWGT ON OFF

- installed and operational by 1991
- construction during 1989, 1990, 1991
- $56.5 m. (1982)[1] - $16.95, $22.6, $16.95
- increased operating cost of $5.466 m.
- no increase in acid production

Inco Alternative (RRS using IORP)[2]

- operational by 1992
- construction for six years ending in 1992:
  1987, 1988, 1989, 1990, 1991, 1992
- $430 m. (1982)[1] $43.0, $43.0, $64.5, $64.5, $86.0, $129.0
- operating cost savings of $24.9 m. (Appendix 8.3)
- decrease in acid production of 215.7 tonnes (000's) per annum

NRWGT on IORP

- installed and operational by 1991
- construction during 1989, 1990, 1991
- $41.0 m. (1982)[1] - $12.3, $16.4, $12.3
- increased operating cost of $5.646 m. ($54.7)
- no increase in acid production

All Programs

- planning horizon extends to year 2015
- additional revenues from potentially more efficient metal recoveries were ignored as well as potential revenues lost through the rejection of ores with high sulphur content
- smelter acid was assumed to yield a net back of zero to the firm
- additional mine development costs associated with some options were not assessed

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[1] All costs are given in 1982 Canadian dollars.

[2] Inco alternative has a higher capital cost of $250 to $300 million than roast/reduction smelting due to need for materials handling equipment and other factors not considered in roast/reduction smelting. However, operating cost savings were estimated to be on the same basis. A detailed discussion of the differences is contained in Appendix 4.2.

APPENDIX 8.2

SUMMARY OF CAPITAL AND OPERATION COST ASSUMPTIONS FALCONBRIDGE

Increased Pyrrhotite Rejection

- immediate effect in 1983
- capital construction of $3.5 m. in 1990 to be operation in 1991
- operating savings of $2.8 m. increasing to $4.2 million in 1990
- decrease in acid production of up to 90.8 tonnes (000's) per annum

Increased Roast

- immediate effect in 1983
- capital construction required of $4.5 m. in 1983 followed by $10.95 m. in 1989 and $10.95 m. in 1990
- operating cost of $.4 m. increasing to $1.2 m. in 1990
- increased acid production of up to 92.7 tonnes (000's) per annum

Roast/Reduction Smelting

- installed and operational by 1990
- capital construction - 1988, 1989, 1990
- $46 m. (1982)[1] - $13.68, $18.24, $13.685
- increased acid production by 190.5 tonnes (000's) per annum

Direct Conversion to Acid

- installed and operational by 1986
- capital construction - 1983, 1984, 1985, 1986
- $52 m. (1982)[1] - $5.19, $10.38, $20.76, $15.57
- increased operating cost of $3.3 m
- increased acid production of 158.4 tonnes (000's) per annum

Regenerative Weak Gas Treatment

- installed and operational by 1986
- capital construction - 1984, 1985, 1986
- $48 m. (1982)[1] - $14.49, $19.32, $14.49
- increased operating cost from $12.4 m. to 14.0 m.
- increased acid production by 210.9 tonnes (000's) per annum

Non-Regenerative Weak Gas Treatment

- installed and operational by 1986
- capital construction - 1984, 1985, 1986
- $47 m. (1982)[1] - $13.95, $18.6, $13.95
- increased operating cost of $15.1 m.
- no increased acid production

Pyrrhotite Rejection (RWGT plus)

- installed and operational by 1987
- capital costs/construction - 1985, 1986, 1987
- $35 m. (1982)[1] - $10.35, $13.8, $10.35
- increased operating cost of $9.0 m.
- increased acid production of 45.2 tonnes (000's) per annum

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[1] All costs are given in 1982 Canadian dollars.

APPENDIX 8.2 (continued)

Increased Roast (RWGT plus)

- installed and operational by 1987
- capital/construction - 1985, 1986, 1987
- \$62 m. (1982)[1] - \$18.66, \$24.88, \$18.66
- increased operating cost of \$14.4 m.
- increased acid production of 215.7 tonnes (000's) per annum

All Programs

- planning horizon extends to year 2020
- additional revenues from potentially more efficient metal recoveries were ignored as well as potential revenues lost through the rejection of ores with high sulphur content
- smelter acid was assumed to yield a net back of zero to the firm
- additional mine development costs associated with some options were not assessed

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[1] All costs are given in 1982 Canadian dollars.

APPENDIX 8.3

SUMMARY OF ANTICIPATED COST SAVINGS

Additional Cost of Materials
(Paste, Catalyst + Maintenance Materials of 4.6 million per annum)

	Actual Cost
- RRS	5.92
- OFF	5.3

Decrease in Labour Cost (Inco Estimated Present Process Cost of $28.3 million minus Labour Force Estimates for Operating and Maintenance, but excluding Supervisory/ Administration Staff)

	Decreased Cost	Actual Cost
- RRS	20.7	(7.6)
- OFF	21.3	(7.0)

Decrease in Energy Cost for Smelters, Converters, Indirect (Waste Heat Boilers) Energy, Acid Plant, Coke (reduction +/heat value) minus Steam Credit from Present Process Cost of $28.73 million per annum

	Decreased Cost	Actual Cost
- RRS	18.6	10.13
- OFF	23.2	5.58

	SNC
- RRS	24.91
- OFF	21.5

9. REVIEW OF THE ENVIRONMENTAL SITUATION

Abstract

The impact of Sudbury's emissions on the natural environment is examined in two different regimes - local, (i.e. within about 100 km) and at longer distances (i.e. greater than about 150 km). On the local scale, the deterioration of Sudbury's forests and lakes caused by emissions of sulphur compounds and associated trace metals commenced with the opening of the Basin's smelting operations in 1888. Smelter production increased throughout the 1930's, the 1950's and the 1960's with an associated increase in emissions of sulphur compounds and trace metals. Again, those industrial developments were followed by increased environmental damage. Erosion, which had started with earlier forest damage, continued to strip the protective soil cover away and eventually the vegetation thinned and disappeared. Recently, SO_2 vegetation injury from frequent high sulphur dioxide ground level concentrations of short duration has been largely ameliorated by abatement practices and the commissioning of the tall stack in 1972.

Nearly a century of smelting has severely damaged many of the local lakes, exhausting their ability to neutralize additional acid input. These affected lakes represent the end result of past and present Sudbury area emissions. Taller stacks have transferred the bulk of present SO_2 emissions out of the Sudbury area to other regions of Ontario and northeastern North America where they now contribute to the acidic deposition problem.

The acidified water bodies in the Sudbury area are expected to continue to respond favourably to decreases in SO_2 emissions from the smelters. However, to protect and improve these lakes as well as lakes in other areas, a further significant reduction in the SO_2 emissions from sources far away from Sudbury is also required.

The additional problem of metals, mobilized by the interaction of acidic compounds with the environment, can only be solved by decreasing current metal emissions and by a general transboundary acid gas control program. Such a program would include SO_2 controls on the Sudbury smelters.

Metal contamination of soils and lakes is an additional concern in the near field, i.e. closer to Sudbury. Reductions of copper and nickel emissions by about 90% are required to protect the Sudbury aquatic environment.

The emissions from Sudbury also have an impact on ecosystems which are far removed from its sources. In recent years, the contribution of these and other sources in eastern North America to the impact on various ecosystems

has been the focus of public concern. Sudbury's emissions are shown to be a part of the long range transport of "acid rain" and for many of the sensitive ecosystems identified by the Canada/US Memorandum of Intent Work Groups, Sudbury is recognized as a significant single contributor to the deposition of sulphur compounds. For instance, in the Muskoka-Haliburton region of Southern Ontario, Sudbury contributes about 19% of the total sulphur deposition, while in Southern Nova Scotia, its contribution is about 6%.

The damage to ecosystems from long range transport can be varied, covering structural deterioration, damage to lakes and fisheries, lower crop yields or alterations in forest growth. Damage is also occurring over large geographic areas; thus, the economic impact may be quite severe. While a reduction in loadings which lead to acidification can be achieved by dramatically reducing Sudbury's emissions, no sensitive ecosystem can be fully protected without reductions in the emissions from other U.S. and Canadian sources.

The impact of current fugitive smelter emissions on the workplace environment is briefly discussed with respect to the occupational threshold limit values of the Ontario Ministry of Labour. Better containment of off-gases, especially from the converters, is expected to reduce SO_2 and particulate levels in the workplace.

9.1. Introduction

Sections of this Chapter explore the past impacts of Sudbury's smelters on the local environment and quantify the contribution of these smelters to the present long range transport of acidic compounds. The local impacts are discussed in Sections 9.2 through 9.6; the long range impacts are discussed in Section 9.7. With this information, it should then be possible to identify the change in sulphate deposition rates derived from emission reductions. A more detailed presentation and discussion of the impact of local smelter emissions on the Sudbury environment is available in an Ontario Ministry of the Environment report based on studies in the Sudbury area from 1973 to 1980.[1] Part of this Chapter provides a summary of the information presented in that report. Similarly, a wealth of information on the effects due to long range transport and the causes of the "acid rain" problem is available in the public literature. This Chapter will not discuss this material in depth. The reader is referred to the set of reports compiled by the U.S. and Canadian governments under the 1980 Memorandum of Intent for a more detailed discussion of the long range transport phenomenon.

An evaluation of the environmental benefits from smelter emission reductions for Sudbury's lakes and forests cannot be undertaken without an understanding of the damages inflicted over the past hundred years. These damages are a result of historic and continuing emissions and a function of the local geology and meteorology. The resiliency of much of the Sudbury area ecosystem has been severely strained. Emission reductions effected during the 1970's, as outlined in Chapter 2, have resulted in some improvement to the local environment; further recovery, however, will not be realized unless acidic deposition rates are reduced to levels acceptable to sensitive ecosystems in the Sudbury area. Although other areas of the province are as sensitive to acidic deposition as the Sudbury area, they have not been exposed to the same cumulative and exhausting loadings.

In addition to discussing the effects of the Sudbury smelter emissions on the natural environment, the impact of current fugitive emissions on the workplace environment is also an area of concern. Section 9.8 of this Chapter addresses this issue, but to a limited extent only.

[1] ONTARIO MINISTRY OF THE ENVIRONMENT, 1982. Sudbury Environmental Study Synopsis: 1973-1980. Prepared for the Ontario Ministry of the Environment Sudbury Environmental Study. Toronto, Ontario: Ontario Ministry of the Environment, Acidic Precipitation in Ontario Study Coordination Office, 1982.

9.2 Historical Damages to the Natural Environment

In the early years of Sudbury's mining activity (1888-1930), ore was roasted in open heaps resulting in elevated ground level concentrations of SO_2 adjacent to the heaps. Approximately 25.4 million tonnes of ore had been smelted by 1930, resulting in the release of about 10.2 million tonnes of SO_2.

These emissions were extremely damaging to local vegetation, initiating a cycle of events which has resulted in the present largely denuded Sudbury landscape. Sensitive agricultural crops and forest species (trembling aspen, white birch and white pine) exhibited both acute (short-term) and chronic (long-term) damage from atmospheric SO_2 up to a distance of 40 km northeast of Sudbury. This damage was measured in terms of foliage, bark and biological injuries, decreased radial and volume growth rates and tree mortality. Slight chronic injury was observed on eastern white pine trees at a distance of up to 65 km northeast of Sudbury.

In turn, this weakened vegetation was more prone to the forest fires which were frequent occurrences in the Sudbury area at that time. Any fresh growth which developed following a fire or extensive logging operations was more susceptible to sulphur dioxide fumigations. The sites where vegetation was killed became vulnerable to the forces of erosion which stripped much of the soil from the hills. The loss of soil, plus the metallic contamination of the remaining pockets of soil, made conditions very difficult for maintaining a vegetation cover on the rocky hills around Sudbury.

The end result of the emissions from Sudbury smelting operations was the creation of large barren areas virtually devoid of trees and other vegetation. The severity of the damage was dictated by distance from the smelter and microclimatic conditions.

The acidification of Sudbury area lakes is also linked to heavy historical emissions of SO_2. Sulphuric acid and other acid-causing sulphur compounds have been washed into the local water systems where they were concentrated over almost 100 years. However, the resultant environmental impacts were not recognized until the 1960's, when studies began to document the existence of high sulphate and abnormally low pH levels in many lakes. As well, many area lakes were contaminated with potentially toxic levels of trace metals, especially copper.

Subsequent investigations showed that 70 of 150 lakes in the La Cloche Mountains (50 to 100 km southwest of Sudbury) had pH levels less than 5.5, with 33 of these exhibiting a pH reading below 4.4. In addition, many lakes equally distant from Sudbury in a northeasterly direction were also acidic.

Recognizing the need to better quantify the breadth and scope of the environmental impact on the aquatic ecosystems in the Sudbury area, the Ontario Ministry of the Environment and the Ontario Ministry of Natural Resources began a major investigative study in 1973 (the Sudbury Environmental Study - SES). The results of these aquatic related investigations are presented in some of the subsequent Sections of this Chapter.

From an historic perspective, it can be concluded that the emissions from smelting operations in Sudbury, beginning at the turn of the century, have caused significant and severe environmental impacts within 100 km of Sudbury.

9.3 Acute Vegetation Damage

Acute or short-term damage to eastern white pine forests in the local Sudbury area (within 40 km) due to high ambient SO_2 concentrations has decreased markedly in recent years.

Early work on acute vegetation injury based on ground level SO_2 measurements defined the boundaries of this type of impact. The effects of potentially injurious fumigations were found to depend on climatic conditions, seasonal susceptibility of the vegetation and relative humidity.

On the basis of observations of the extent of injury to vegetation in areas adjacent to SO_2 monitoring stations, investigators found that injury could occur in response to the SO_2 doses listed in Table 9.1.

The results of investigations conducted by the Ontario Ministry of the Environment from 1970 to 1981 demonstrate that abatement measures taken by both Inco Limited and Falconbridge Limited have substantially reduced the number of potentially injurious fumigations (as illustrated in Figure 9.1). These measures entailed reducing the gross amount of SO_2 emitted, enhancing its dispersion through the use of tall stacks (Inco Limited) and curtailing operations during unfavourable atmospheric conditions (Inco Limited).

Since 1978, cessation of operations due to labour strikes and/or production shutdowns has substantially reduced SO_2 emissions during some of the summer growing seasons.

With respect to vegetation damage, the data have indicated that, in the years prior to 1972, acute and chronic vegetation injury occurred within an elliptical area which had its outermost limit at a distance of 70 km northeast of Sudbury. Vegetation injury since 1972 has been reduced to the extent that current injury occurs infrequently, being confined to relatively small isolated areas and affecting only those plant species which are most sensitive to SO_2.

9.4 Metal Contamination

On average, between 1973 and 1981, the smelters in Sudbury annually emitted about 1,800 tonnes of iron, 670 tonnes of copper and 500 tonnes of nickel. Between 70% and 80% of the copper and nickel is deposited within 40 km of Sudbury. The actual deposition is dependent on the distance from the stacks and the prevailing winds.

9.4.1 Metals in Terrestrial Systems

Foliage samples of low sweet blueberry, red maple and wavy hair-grass collected at distances of up to 50 km along a transect from Inco's Coniston smelter were found to have elevated concentrations of nickel and copper. For all three species, the levels of nickel, copper and iron decreased markedly with distance from the smelter.

Aluminum concentrations in foliage of wavy hair-grass suggested an impact from smelter emissions. Recent emissions data indicate that aluminum is emitted in substantial quantities from both the Inco and Falconbridge smelters. However, a clear relationship with emissions could not be supported due to the very limited data base and the interrelationship between soil pH and the uptake of aluminum by plants.

The Coniston smelter study also revealed that the lowest soil pH values occurred in the surface soils, with pH increasing with increasing depth in the soil profile. The pH values of surface soils up to 7.4 km from the Coniston smelter, which was shut down permanently in 1972, were generally less than 3.0. (The pH of natural Canadian Shield podzolic soils is in the range of 3.5 to 4.5). Significant soil concentration/distance relations were observed for copper (Cu), nickel (Ni), cobalt (Co), silver (Ag) and iron (Fe), whereas no obvious pattern could be established for zinc (Zn), manganese (Mn), aluminum (Al) and vanadium (V). A marked soil depth profile effect was shown for nickel, copper and cobalt, with the highest concentrations usually occurring in the surface soils. Soil distribution patterns for lead (Pb) were less marked, whereas very little evidence of surface soil loading for zinc and manganese could be found. In general, metals in soils are mobilized or become more available for uptake by plants as the soil becomes increasingly acidic.

Field studies to determine the elemental composition of vegetation foliage samples were initiated during the 1970 growing season by the Ministry with the establishment of a number of permanent vegetation sampling plots in the territory affected by the Sudbury area smelters (Figure 9.2) and a few control plots in areas remote from Sudbury. Concentrations of various chemical elements in plant species and soil at increasing distances from the smelters were determined over the period 1970 to 1976.

The results of the vegetation and soil sampling program conducted by the Ontario Ministry of the Environment between 1970 to 1976 are summarized as follows:

- Excessive concentrations of nickel and copper were frequently found in soil and vegetation samples collected at Sudbury, Garson and Skead, i.e. within about 20 km from the smelters. Excessive concentrations of these two metals were also found in some samples collected at slightly greater distances from the smelters (Rayside, Tilton Lake, Callum and Kukagami Lake). Most soil samples collected in the Sudbury study area contained elevated copper concentrations in relation to the control samples. A decline in the average concentration of sulphur in vegetation samples collected in the Sudbury area was observed after 1972.

- A limited number of vegetation samples contained excessive levels of arsenic (As) or selenium (Se) and, again, these samples were collected in close proximity to the smelters. Lead, zinc and fluoride concentrations were within normal limits for the respective plant species.

- At Skead and Garson, several soil samples contained excessive amounts of arsenic. Soil samples from Sudbury (1972) and Garson (1970) contained the highest concentrations of selenium, but these were not considered to be excessive. However, some values for these elements were elevated in relation to control sample values. Calcium and magnesium values for the soil samples were low and were considered to be related to low soil pH values.

- The soil pH was found to be low at all sampling locations in the study area, including the pH values obtained at control locations (Blind River and Mattawa). Considerable variation in pH values was noted from collection to collection, with the majority of samples having pH values in the range of 4.0 to 5.5.

The greatest impact on soils in the immediate Sudbury area was observed to be from copper and nickel, which were often present in excessive amounts. Their concentrations were found to decrease with increasing distance from the smelters. More recent studies suggest that the degree of contamination is slowly decreasing as a result of reduced emissions.

Although the data base is limited with respect to contamination of vegetation and soils by aluminum in the Sudbury Basin, the level of local emissions from the smelting operations and total deposition of aluminum in this area could be significant. This concern is based on recent findings in Central Europe regarding the mobilization of aluminum ions in soils as a result of acid precipitation and its adverse impact on soils and forest ecosystems. Studies to investigate the possible impact of aluminum on vegetation and soils in the Sudbury area are presently underway as part of Ontario's acid rain program.

The extensive buildup or accumulation of metals in the soil close to the Sudbury area smelters is aggravated by the increase in soil acidity and could result in:

- significant changes in soil composition and its micromorphological (physical) structure and chemistry;
- severely reduced levels of soil microflora and microfauna;
- the alteration of soil nutrient cycles;
- severe restriction of the vegetation regenerative potential of these soils.

As is the case for vegetation, some reduction in soil contamination has been noted since 1972, and recent revegetation efforts on barren soil areas are proving successful when soil ameliorative techniques (liming, fertilizing and seeding) are employed. Since 1978, a large scale land reclamation project has been carried out in the Sudbury area and some 1,550 hectares (about 3,830 acres) have been limed, fertilized and seeded to grass. The cleanup of damaged sites and development of grass cover have been judged to be highly effective in improving the appearance and the environment of the Sudbury area.

9.4.2 Metals in Aquatic Systems

The concentrations of nickel and copper in the lakes surveyed from 1974 to 1976 indicated that significant contributions of these metals were probably due to the Sudbury area emissions, while the concentrations of cadmium, lead, iron and zinc appeared to be controlled primarily by geological factors. From a toxicity viewpoint, copper was the only metal that reached concentrations exceeding Ministry of the Environment Objectives for the protection of fish and aquatic life. These levels were recorded in 15% of the lakes sampled. Levels of aluminum and possibly cadmium also reached levels shown to be toxic to fish in laboratory studies.

Bulk deposition measurements performed in the study area from 1976 to 1979 revealed an exceptionally high input of Cu, Ni, Zn, Fe, Mn, and Al to the SES study lakes (Figure 9.3). During the period that Inco Limited was shut down due to a strike, bulk deposition of Cu and Ni fell to levels as low as those recorded at Muskoka-Haliburton, 225 km distant from Sudbury. Almost all of the Cu, Ni and Zn, and some of the Fe inputs to the lakes, were found to result from direct atmospheric deposition. Further, the atmospheric deposition of acidifying substances has increased the output of Al, Mn and Fe from the watersheds to the lakes.

Average concentrations of Cu, Ni, Zn, Al and Mn in Clearwater Lake in 1977 were 81, 278, 39, 381 and 290 micrograms per litre respectively. Trace metal concentrations decreased in the six other study lakes with increasing distance from Sudbury, but even in Mountaintop Lake, 50 km from the city, the levels of Zn, Cu and Ni were well above background levels and levels measured in south-central Ontario lakes which are removed from industrial centres but still receive acidic precipitation.

On the basis of the best available information on the environmental impact associated with the elevated metal deposition rates observed in the Sudbury area, it is fairly evident that the most sensitive receptors are the aquatic ecosystems. There is ample documentation to indicate severe stress on many Sudbury area lakes due to elevated concentrations of metals.

The concentrations of Cu, Ni and Pb in the lake sediments were observed to have increased by one to two orders of magnitude relative to background levels. Cd, Fe, and Zn concentrations also increased, but by lesser amounts, generally by one order of magnitude. The deposition rates to the sediments of Cu, Ni and Pb were also found to have increased by one to two orders of magnitude relative to background levels. These increases were found to coincide with a decrease in the concentration of Al in lake sediments. Acidification of the interstitial water of the surficial sediments results in the leaching of Al. The major changes in Cu, Ni, Cd, Fe, Zn, Pb, and Al occurred simultaneously, approximately 50 (plus or minus 15) years ago. These changes appear to coincide chronologically with the increased level of activity of the smelting industry referred to earlier.

The sedimentation rates in several Sudbury Environmental Study lakes increased dramatically (by 200 to 400%) about 40 to 50 years ago. This period roughly coincides with the opening of the Falconbridge smelter, increases in the total nickel production and in associated emissions in the Sudbury Basin, and the commissioning of taller stacks at the Copper Cliff smelter.

These taller stacks are believed to have extended the zone of impact of the emissions, previously limited, in large part, to distances very close to the smelters (less than about 10 km). This resulted in a considerably greater impact on some of the watersheds in the greater Sudbury area. Prior to these changes, the sedimentation rates were typical for oligotrophic Precambrian Lakes (5 to 10 mg cm^{-2} yr^{-1}). The sedimentation rates, as determined by cores that had no mixing zone in the upper layers, have declined to the early levels over approximately the last two decades.

The extra sediment responsible for these increased sedimentation rates is believed to consist of material displaced from the lakes' watersheds as a result of increased leaching and erosion of the overburden in these watersheds. In turn, the increased leaching and erosion probably resulted from increased input of acid producing substances to the watersheds, largely related to the emissions from Sudbury area smelters, and also from the impact of the smelting and lumbering activities on the vegetation at that time. While sedimentation rates have decreased to historic levels over the past two decades (with the exhaustion of some of the area's soil cover), metal deposition rates have only decreased with production cutbacks and abatement programs instituted in the 1970's.

In order to reduce metal concentrations in the Sudbury lakes to those specified as acceptable by the Great Lakes Water Quality Objectives, direct atmospheric inputs of Cu and Ni must be reduced by about 90% and inputs of Fe and Zn by 50% to 60%. However, some of this Fe and Zn is released from the watersheds to the lakes as a result of the atmospheric deposition of sulphate, such that emission reductions somewhat less than 50% to 60% are required for these elements[2]. A 70% reduction in watershed output of Al is required to decrease lake concentrations of Al to 100 micrograms per litre. Such a reduction in Al outputs can only be achieved by a large reduction in the deposition of sulphate.

Many Sudbury area lakes suffer from copper and nickel concentrations that rank among the world's highest. Emission abatement can reduce loadings but acidic deposition must be controlled if further trace metal mobilization is to be minimized in the lakes and their watersheds.

[2] Metal toxicity to aquatic life is generally higher for soft (low carbonate content) waters than for hard (high carbonate content) waters since in hard waters some of the metals can be complexed as carbonates preventing metal uptake in toxic form by aquatic life. Hence, the Great Lakes Water Quality Objectives may be too high for soft waters such as those in the Sudbury area which means that the recommended reductions in metal emissions may still be inadequate. In addition, the synergistic effects of several metals have not been considered.

9.5 Atmospheric Sulphur Deposition

Substances, whether in the gaseous or particulate form, emitted to the atmosphere eventually reach the earth's surface as a result of atmospheric deposition processes. Deposition values are usually expressed as the mass flux of material to the earth's surface in units of kilograms/hectare·year. If the deposition occurs as a result of scavenging by rain or snow, the deposition is termed "wet". In the absence of precipitation, deposition occurs through dry processes. Total deposition is the sum of the wet and dry contributions.

Wet deposition values can be measured by using a collector which is open only during periods of precipitation and then, by determining the concentration of substances in the precipitation samples. Bulk deposition measurements, which use a continuously open collector (as compared to one which is open only during precipitation periods), have also been used in the Sudbury area to estimate atmospheric loading rates to lake basins. Bulk deposition includes both wet deposition and an (unknown) fraction of the particulate material which eventually reaches the earth's surface. In addition, measurements have been made on both an event and longer term basis, as discussed below.

Direct measurement of atmospheric dry deposition is extremely difficult and no method presently exists that is suitable for routine field use. A commonly used approach is to measure the ambient ground level concentration of substances of interest and then to estimate the deposition flux from the product of the concentration and the "deposition velocity", although for most substances there are large uncertainties in the latter quantity.

The sulphur present in the substances that eventually reach the earth's surface undergoes chemical transformation processes (oxidation), the result of which is the formation of sulphate (SO_4^{2-}) compounds. Hence, a commonly used approach is to express sulphur deposition as an equivalent SO_4^{2-} deposition, which is the approach used in this Chapter.

The emphasis on SO_4^{2-} deposition is easily justifiable as studies of lakes in eastern North America have provided ample evidence that atmospheric deposition accounts for sulphate levels in excess of those expected from natural processes. Work summarized in the U.S./Canada Memorandum of Intent reports has identified sulphuric acid as the dominant compound contributing to the long-term surface water acidification process. Nitric acid contributes to the acidity of precipitation, but is much less important than sulphuric acid in long-term acidification of surface waters. Nitric acid contributes to surface water acidification particularly during periods of snow melt in some areas. The atmospheric deposition data and lake monitoring data collected in the Sudbury area support this conclusion.

Atmospheric deposition models have been developed by the Ontario Ministry of the Environment in connection with the Sudbury Environmental Study to estimate, in the long term, the short range (within 100 km of Sudbury) and the long range contributions to the atmospheric deposition of substances emitted from Sudbury area smelters.

The results of the estimates of sulphate deposition rates at a few locations in the Sudbury area, and also in the Muskoka-Haliburton area, largely over the period June 1977 to May 1978, are presented in a report released by the Ontario Ministry of the Environment[3] and are summarized below:

- The dry component of total SO_4^{2-} deposition in the Sudbury area is highly variable. At some locations in the immediate Sudbury area (about 10 km from the Copper Cliff smelter), the dry component of total SO_4^{2-} deposition can be as much as four times higher than the wet component as a result of the dry deposition of SO_2 emitted from the local smelter sources. At other locations (equally close to the Copper Cliff smelter), the dry contribution to total SO_4^{2-} deposition is much lower (dry component is about 1.4 times the wet component). The results reflect the dominance of westerly and southwesterly winds in the Sudbury area.

- The Sudbury contributions to total SO_4^{2-} deposition in the immediate (10 km) Sudbury area, when Inco and Falconbridge are operating, are significant, ranging from 36% to about 70%; the major contribution from Sudbury sources is the dry component which ranges from 32% to about 68% of the total sulphate deposition, within about 10 km from the Copper Cliff smelter.

- The Sudbury contributions to dry deposition are estimated to decrease rapidly with increasing distance from the smelters, approaching background levels (19 kg SO_4^{2-}/ha·yr) at distances of less than 50 km from the Copper Cliff smelter for all directions, except for the northeast and east quadrants, where local contributions do not reach 'background' levels for at least 100 km.

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[3] Op. cit.

- Sudbury sources contribute, on average, about 10% of the total wet sulphate deposition within a 40 km radius.

- On the assumption that Sudbury contributions to both wet and dry deposition are completely eliminated, the Sudbury area within a 40 km radius would be exposed to total sulphate deposition rates of about 46 kg SO_4^{2-}/ha·yr (wet = 27 kg SO_4/ha·yr and dry = 19 kg SO_4^{2-}/ha·yr) based on 1977 SO_2 emission levels for 'outside' sources.

- Sudbury SO_2 emissions contributed 7.4 kg SO_4^{2-}/ha·yr or 19.4% of the total sulphate deposition in the Muskoka-Haliburton area, based on 1980 emission levels. Other continental SO_2 sources are estimated to result in a total deposition rate of about 30 kg SO_4^{2-}/ha·yr in that area.

- Since long range transport is estimated to account for almost half of the problem, additional improvements could be derived by concurrently effecting SO_2 emission reductions for the other contributing sources of deposition in the Sudbury area.

9.6 Lake Acidification in the Sudbury Area

9.6.1. Surface Water Quality Impacts

The lakes of the Sudbury area have been subjected to a heavy input of sulphur compounds for nearly a century. For many, their ability to buffer incoming acid has been exhausted and their major supply of fresh buffering capacity comes from chemical weathering by strong acid precipitation. Small inputs of sulphuric acid or other acid-producing substances not completely assimilated (neutralized) by receiving waters are sufficient to cause a significant long-term pH reduction in some of these dilute northern lakes.

The refinement of calibrated watershed studies in recent years has indicated that locally contributed dry SO_2 deposition is equally important to other forms of acidic deposition in reducing pH (see Section 9.5). The concentration of SO_4^{2-} is higher in Sudbury lakes than in south-central Ontario lakes and decreases with increasing distance from Sudbury.

Of more than 200 lakes investigated covering a radius of 200 km from Sudbury, 20% had calcite saturation indices of greater than 5.0 (CSI - a measure of H^+ assimilation capacity) indicating that they had been critically acidified. An additional 50% had CSI's in the range of 3.0 to 5.0, indicating vulnerability to continuing acidic inputs. The distribution of low pH (pH less than 5.5) lakes was found to exhibit a distinct northeast/southwest pattern with respect to the location of the Sudbury area smelters. This distribution pattern reflects the highly weathering resistant local geology and coincides with observed prevailing surface wind directions. This low pH zone-of-effect occupies an area of 5,300 km^2 amounting to a total lake surface area of about 650 km^2.

Within this zone, which includes 30% of the study lakes, significant losses and depression of fish populations and associated biota have occurred.

As indicated in Chapter 2, total SO_2 emissions from the Sudbury area smelters have decreased substantially in the last decade. Because of the large local contribution to sulphate deposition to Sudbury area lakes, in time, a corresponding reduction in the sulphate levels of those lake waters would be expected. Figure 9.4 illustrates this relationship for Clearwater Lake and shows evidence of a lag period of a least several years between emission reductions and reductions in sulphate concentrations in lake waters.

Although these data indicate that pollution abatement at the smelters translates into environmental improvement, the atmospheric deposition information referred to in the previous Section shows that control of Sudbury emissions alone is not sufficient to protect the area lakes.

To estimate the number of acidic lakes in the immediate Sudbury area, lake survey data taken in 1981 by the Northeastern Region of the Ontario Ministry of the Environment were used. These lakes were a subset of 250 lakes surveyed on a regional basis. The selection criteria for the large lake set were as follows:

- provision of broad coverage of lakes on a regional scale;
- representation of all potential variations in lake waters due to natural (geological) and anthropogenic (atmospheric) influences;
- inclusion of lakes known to exhibit adverse effects, i.e. extinct or depressed fisheries;
- suitable size to facilitate sampling via float-equipped aircraft.

Sixty-one lakes were surveyed within 50 km of Sudbury, of which 18 (30%) were acidic (TIA is less than 0 microequivalents per litre). Using data on the number of lakes organized by watershed in Ontario, an estimate may be made of the numbers of acidic lakes. Extrapolation of the 30% figure would indicate that 337 acidic lakes, with surface area greater than ten hectares, exist in the immediate area of Sudbury and that 1,209 smaller acidic water bodies exist. Given the uncertainties inherent in these calculations, estimates of 200 to 400 acidic lakes and a minimum of 1,200 smaller acidic water bodies would perhaps be in order. The approximate nature of these values cannot be overemphasized.

Even though these data indicate that Sudbury area lakes would respond favourably to reductions in local emissions, 100% abatement would be insufficient to protect or restore them, since results from the Sudbury Environmental Study demonstrate that up to 50% of the deposition of acid forming substances (expressed as kg SO_4^{2-}/ha·yr) results from long range transport into the Sudbury area.

9.6.2 Biological Impacts

Several investigators have demonstrated that a reduction in lake pH results in a reduction in the richness or diversity of the phytoplankton (floating plant life) community, especially at pH levels less than 5.5. Some of the reduction in richness observed in acidic Sudbury lakes may be attributable to metal contamination.

However, the existence of fewer species of plankton does not necessarily mean that a smaller "crop" grows in a lake. The biomass of the Sudbury lakes with pH less than 5.5, averaged over the ice-free season, did not differ significantly from the biomass measurements taken from Precambrian Shield Lakes with pH greater than 5.5, suggesting that acidification does not result in a reduction in total biomass or productivity.

The causes for these phenomena are not known, however, the following hypotheses have been put forward:

- reduced grazing by invertebrates;
- reduced rates of bacterial decomposition;
- succession to more acid tolerant species;
- localized increases in the supply or availability of nutrients.

Four Sudbury area lakes have been studied to determine the numbers and diversity of bacteria, yeasts and molds. The comparatively low populations of microorganisms found in these ecosystems indicate a low microbial productivity and a slow rate of nutrient recycling. However, differences in counts could not be explained solely by acidity or metal concentrations.

Acidification results in the reduction of the diversity of zooplankton communities similar to phytoplankton communities. The average number of species of planktonic crustacea observed was three to four times less than in biologically similar, non-acidic lakes in Muskoka-Haliburton. Rotifers were much more important components of the zooplankton population than in the non-acidic lakes. In contrast with phytoplankton, zooplankton standing stocks were reduced due to increased sensitivity to depressed pH or vulnerability to the remaining fish species.

The effects of low pH and associated toxicity of increased metal concentrations on fish are probably the most dramatic of the impacts of acidification. The available literature suggests that, below pH 5.5, reproductive success of fish is impaired and at pH less than 5.0, most fish species are eliminated. Comparison of the present pH data with these guidelines indicates that 20% of the surveyed Sudbury lakes are unsuitable for survival of most fish species and an additional 10% may be unsuitable for maintaining viable fish populations.

The aurora trout had its natural habitat in the large zone with depressed pH (less than 5.5). It is now generally accepted that lake acidification has led to the extinction of this subspecies of the brook trout in these lakes.

There is strong evidence to suggest that even less acidic conditions are capable of causing serious harm to fish populations. Brook trout, for instance, have an overall reduction in recruitment of 43% at a pH of 6.0. This change in reproductive capacity consisted of decreases in egg production, egg viability, hatching and fry survival. Equivalent data for a number of other species have been collected.

Fisheries are particularly susceptible to the "spring pulse" loading effect. The buildup of acidic compounds occurs over the winter in the snow cover. The spring thaw flushes this complete load into the water system without the opportunity for any buffering to occur in the watershed.

The pulse can cause a temporary sharp depression in a lake's pH during the spring spawning or hatching period of many fish species. The age/class composition of a fish species usually shifts to older animals as a consequence of failed recruitment into the population. The end result may be the extinction of a fish species in that lake in less than a decade.

The consideration of biological effects of acidic precipitation is compounded by the occurrence of high levels of metals, due to direct input from smelter emissions as well as increased metal dissolution from the sediments at low pH. Chronic effects of sublethal metal levels as well as the additive, and possible synergistic effects of low pH and metals, are of major concern and require considerable research for adequate clarification. High aluminum concentrations due to dissolution in the watershed are responsible for fishkills (through disruptions of the fish's ionic balance and the formation of mucus on gills hampering respiration).

The occurrence of relatively high zinc and copper concentrations (from smelter emissions) in some lakes studied is of concern since these metals are highly toxic to aquatic biota.

Studies by several investigators indicate that the effects of copper on reproduction, growth and survival of fathead minnows are more pronounced in soft water, as less $CaCO_3$ is available for "complexation" of the metal. Furthermore, available data indicate that synergistic toxicity of metals would be expected, especially in soft water, and therefore, although the concentrations of metals present may be low, a metal effect may still exist.

In conclusion, the depressed pH and elevated metal conditions revealed an adverse impact on phytoplankton and zooplankton communities. Many of the Sudbury area lakes were found to be unsuitable for the survival and reproduction of most fish species.

9.7 Long Range Transport and Acid Rain

The "acid rain" impacts to ecosystems far removed from the emission sources of SO_2 are variable, depending on the nature of the ecosystem. Structural damage, loss of fisheries, crop losses or decreases in forest yields are examples of the kinds of impacts which are presently being extensively documented and assessed from both the economic and scientific perspectives. The governments of Ontario, Canada, other provinces and the United States are deeply concerned about the long range transport issue and have instituted major research efforts to document the extent of the problem and to resolve it. At this time, it is not deemed necessary to describe these research efforts in the context of the report. However, it is appropriate to briefly discuss the role that Sudbury plays in the long range transport issue.

The long range - long term statistical model developed by the Ontario Ministry of the Environment was used to estimate changes in total sulphate deposition rates to a number of receptor areas if Sudbury area SO_2 emissions were reduced from an emission level of 2,743 tonnes (3,024 tons) per day to 363 tonnes (400 tons) per day. The present limit on Sudbury SO_2 emissions is 2,916 tonnes (3,215 tons) per day. The 1980 SO_2 emissions inventory was used for all other contributing sources. The results of this model run are presented in Table 9.2 and illustrate the contribution to total sulphate deposition of various Sudbury SO_2 emission levels on key receptor regions throughout the northeastern North American continent. The model estimates were found to be within a factor of two of the observed values and over 60% of the model results were within 35% of the expected values.

The statistical model was also used (1980 SO_2 emissions) to determine the relative contributions of other major North American SO_2 source regions to a number of sensitive receptor areas throughout the northeastern North American continent. The data from this model run are presented in Table 9.3. The model results for some of the sensitive receptor areas in eastern Canada are depicted graphically in Figures 9.5 to 9.9. The data show that the Sudbury region is a major contributor to the total sulphur deposition for receptor areas such as Algoma, Muskoka-Haliburton and Quebec City, surpassed only by contributions from emissions of US EPA Region V. At more distant receptor areas (Southern Nova Scotia, New Hampshire and the Adirondacks), the Sudbury region emissions contribute substantially to total sulphur deposition and to a lesser degree to the total sulphur deposition in areas such as the Boundary Waters Canoe Area, Pennsylvania and the Smokies.

With respect to the environmental consequences of acid rain and long range transport, the extent of lake acidification depends to a great extent on the buffering capacity of the water body or the water's capability to resist a change in pH. Alkalinity is generally used to assess buffering capacity.

As a rough guide to a lake's sensitivity to acidic loadings, the Ministry of the Environment has developed a five stage categorization scheme. The sensitivity categories are somewhat arbitrary since studies which can quantify the acidification rates of lakes of differing buffering capacities are not yet complete. Nevertheless, they are based on current understanding of lake sensitivity and, as such, can assist in determining whether or not a lake is being affected by acid rain.

An acid sensitivity survey of lakes in Ontario was published by the Ministry of the Environment in April 1982, as part of an ongoing lake sampling program. In a total of 2,619 lakes sampled, 118 lakes, or 5%, were found to be acidified to the extent that their ability to support aquatic life is severely limited. In total, 1,690 lakes, 64% of those surveyed, were found to have some sensitivity to acidification (13% were extremely sensitive, 35% were moderately sensitive and 16% were of low sensitivity). Finally, 811 of the lakes surveyed, or 31%, were found to be not sensitive to the cumulative effects of acid rain.

The material presented in this Chapter allows the following conclusions to be derived:

- The largest single source of SO_2 emissions in Canada is the Sudbury region and, therefore, this region is a significant contributor to sulphur deposition in sensitive receptor areas across eastern North America.

- The contribution to total sulphate deposition from Sudbury sources is greatest on downwind receptor areas, ranging from 19% in Muskoka-Haliburton (at an emission level of 2,721 tonnes of SO_2 per day) to 2.4% at Quebec City (at 363 tonnes per day).

- For regions with no local contribution (e.g. Muskoka-Haliburton), the only way to reduce total sulphate deposition is to require curtailment of SO_2 emissions from a number of major long range point sources. The complete elimination of Sudbury emissions alone would not be sufficient to safeguard the aquatic ecosystems of sensitive receptor regions. However, major reductions in SO_2 emissions from Sudbury would make some of the greatest single contributions to reducing total sulphate deposition in many of the sensitive receptor regions of Ontario.

9.8 Impact on the Workplace Environment

In Ontario, the Ministry of Labour monitors the concentration of contaminants in the workplace to ensure that workers are not exposed to levels of chemical substances that could cause adverse health effects. Threshold limit values are used to refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect.

The threshold limit value presently used by the Ministry of Labour is termed time-weighted average (TWA) and represents the time-weighted average concentration for a normal 8-hour work day or 40-hour work week to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

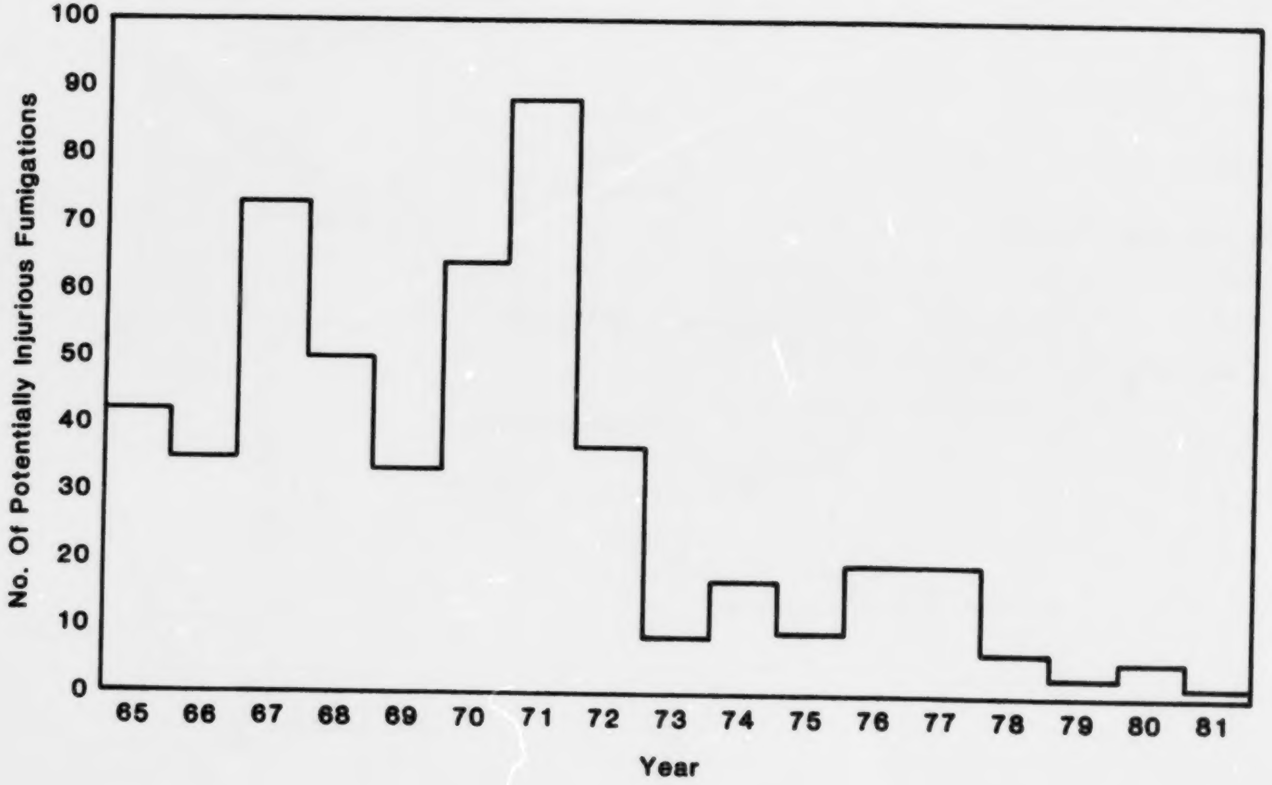
Recently, the Ministry of Labour has developed new guidelines with respect to exposure criteria for potentially harmful agents and substances in workplaces. These new threshold limits, termed time-weighted average exposure criteria (TWAEC), have not been adopted as criteria by regulation under the Occupational Health and Safety Act (OHSA) nor are they legally enforceable limits. They are mentioned here for discussion purposes only. Some of the TWA's and TWAEC's of interest in this report are presented in Table 9.4. On the basis of information for the

Inco and Falconbridge smelters provided by the Ministry of Labour, the ambient concentrations of some of the substances listed in Table 9.4 exceed, from time to time, the TWA limits currently in force under the OHSA. Additional measures have been implemented in both smelters to keep worker exposure below the required TWA limits. Hence, any capital investment or abatement program considered must ensure that the present workroom environment in these smelters is not worsened. In fact, workroom environment conditions will need to be improved substantially for SO_2, especially if the proposed TWAEC's are adopted in the future.

The abatement programs considered in this report are expected to improve, to varying degrees, the workplace environments at Inco and Falconbridge. Better containment of off-gases is anticipated to reduce SO_2 and particulate levels in the workplace. However, it is not possible at this stage to predict the degree of improvement that could be realized by the implementation of any abatement program. That information can only be obtained through detailed in-plant monitoring surveys subsequent to a program's implementation.

FIGURE 9.1

POTENTIALLY INJURIOUS FUMIGATIONS RECORDED IN THE SUDBURY AREA



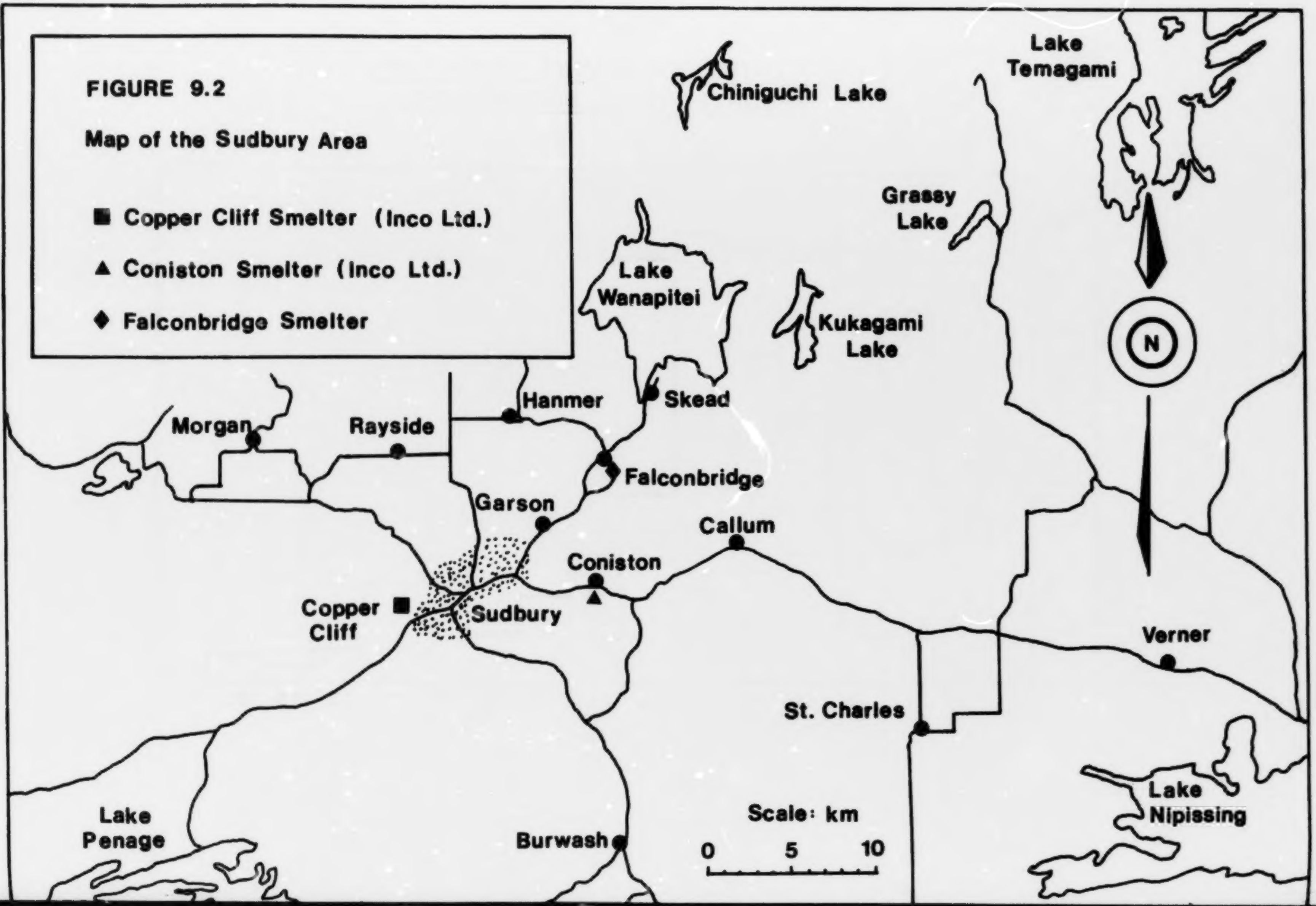


FIGURE 9.2

Map of the Sudbury Area

■ Copper Cliff Smelter (Inco Ltd.)
▲ Coniston Smelter (Inco Ltd.)
◆ Falconbridge Smelter
Lake Temagami
Chiniguchi Lake
Grassy Lake
Lake Wanapitei
Kukagami Lake
N
Skead
Hanmer
Morgan
Rayside
Falconbridge
Garson
Callum
Coniston
Copper Cliff
Sudbury
Verner
St. Charles
Lake Nipissing
Lake Penage
Burwash
Scale: km
0
5
10

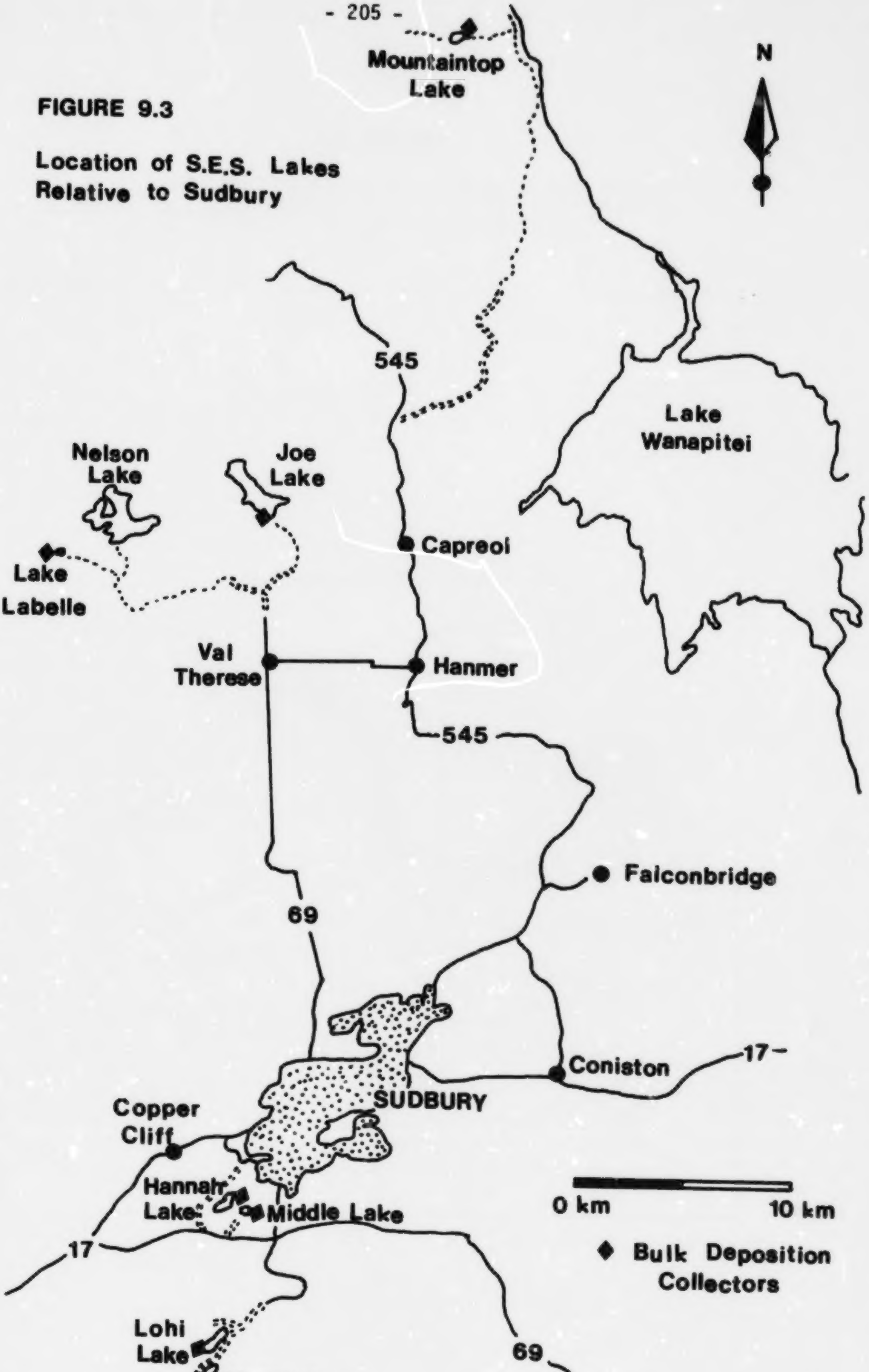


FIGURE 9.3

Location of S.E.S. Lakes Relative to Sudbury

N
Mountaintop Lake
545
Lake Wanapitei
Nelson Lake
Joe Lake
Lake Labelle
Capreol
Val Therese
Hanmer
545
Falconbridge
69
Coniston
17
SUDBURY
Copper Cliff
Hannah Lake
Middle Lake
0 km
10 km
17
◆ Bulk Deposition Collectors
Lohi Lake
69
Clearwater Lake

FIGURE 9.4

THE RELATION BETWEEN LAKE SULPHATE LEVELS AND SMELTER EMISSIONS

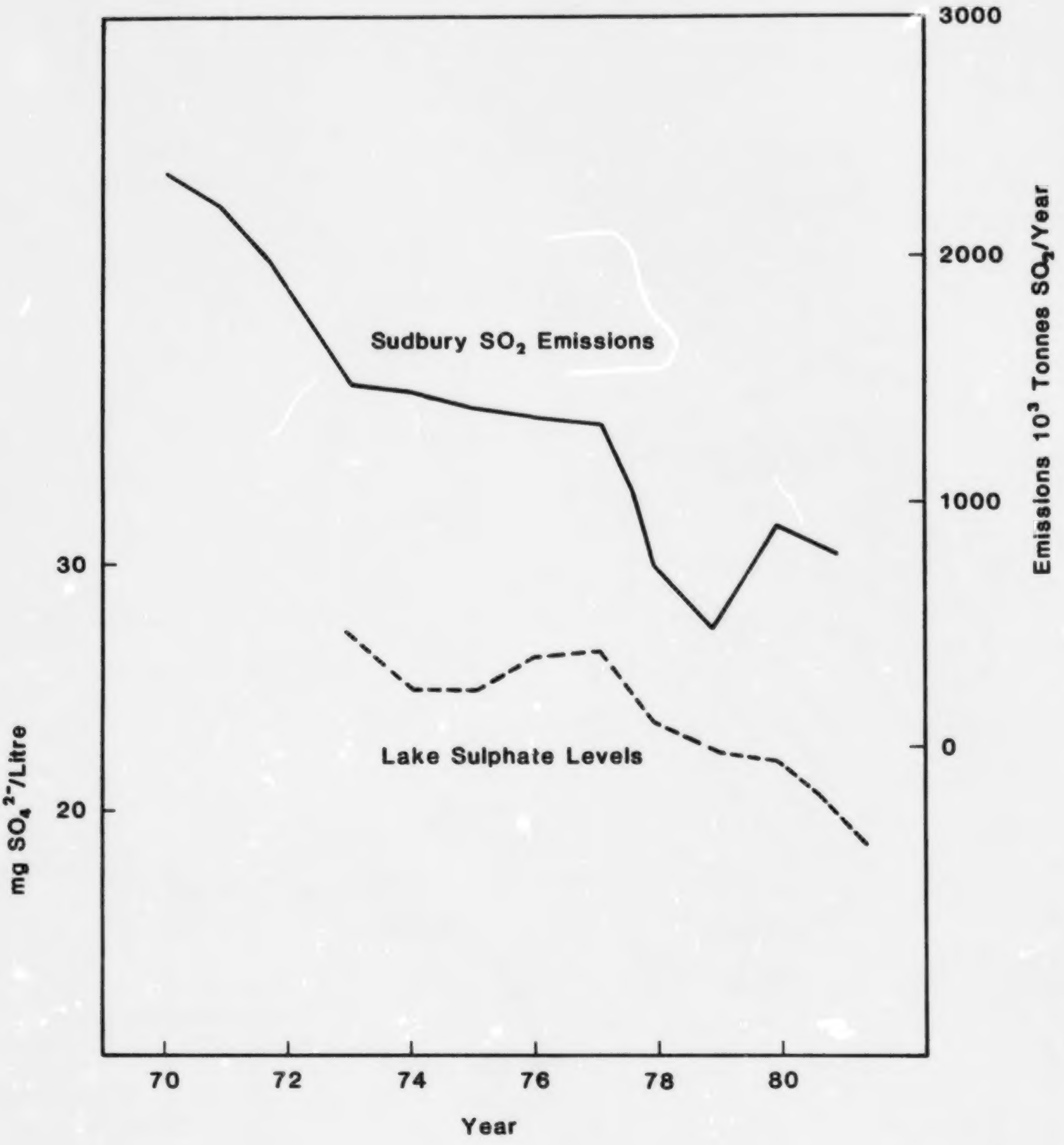
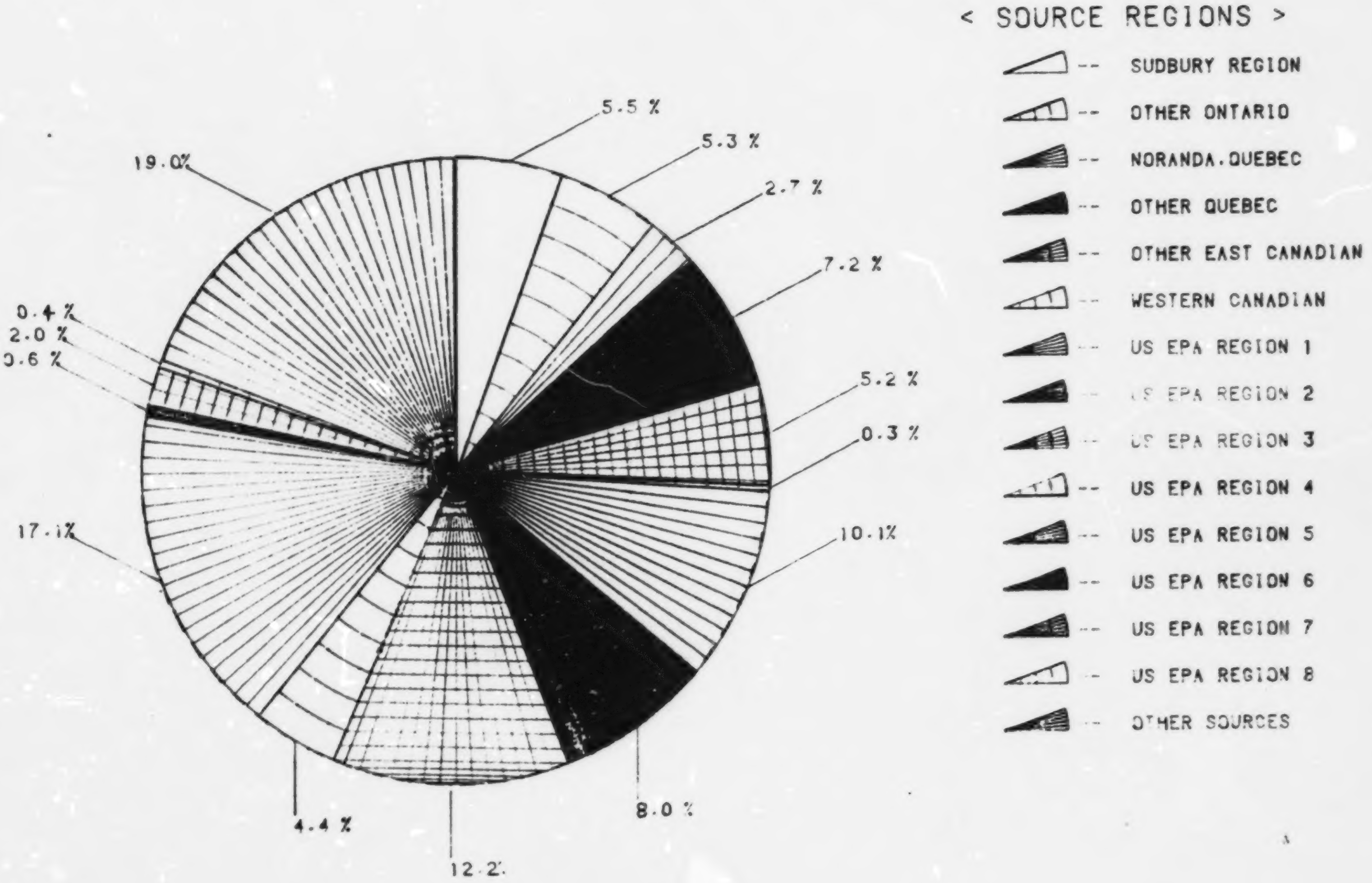


FIGURE 9.5

< PERCENTAGE CONTRIBUTION OF SELECTED REGIONS TO TOTAL SO4 DEP >

RECEPTOR REGIONS: SOUTHERN NOVA SCOTIA



ABSOLUTE DEPOSITION : 33.2
(KG SO4/HA/YR)

FIGURE 9.6

< PERCENTAGE CONTRIBUTION OF SELECTED REGIONS TO TOTAL SO4 DEP >

RECEPTOR REGIONS: QUEBEC CITY

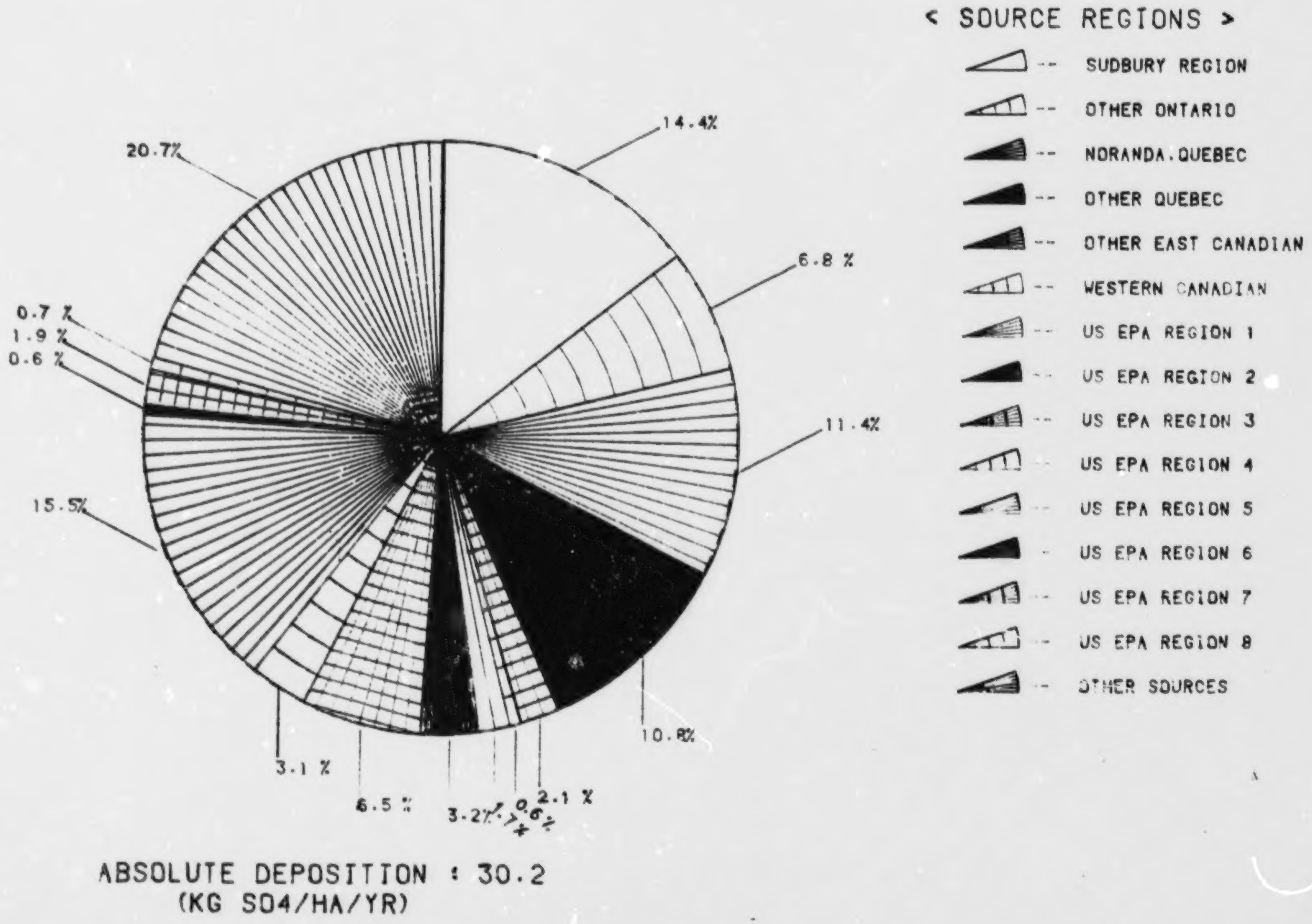
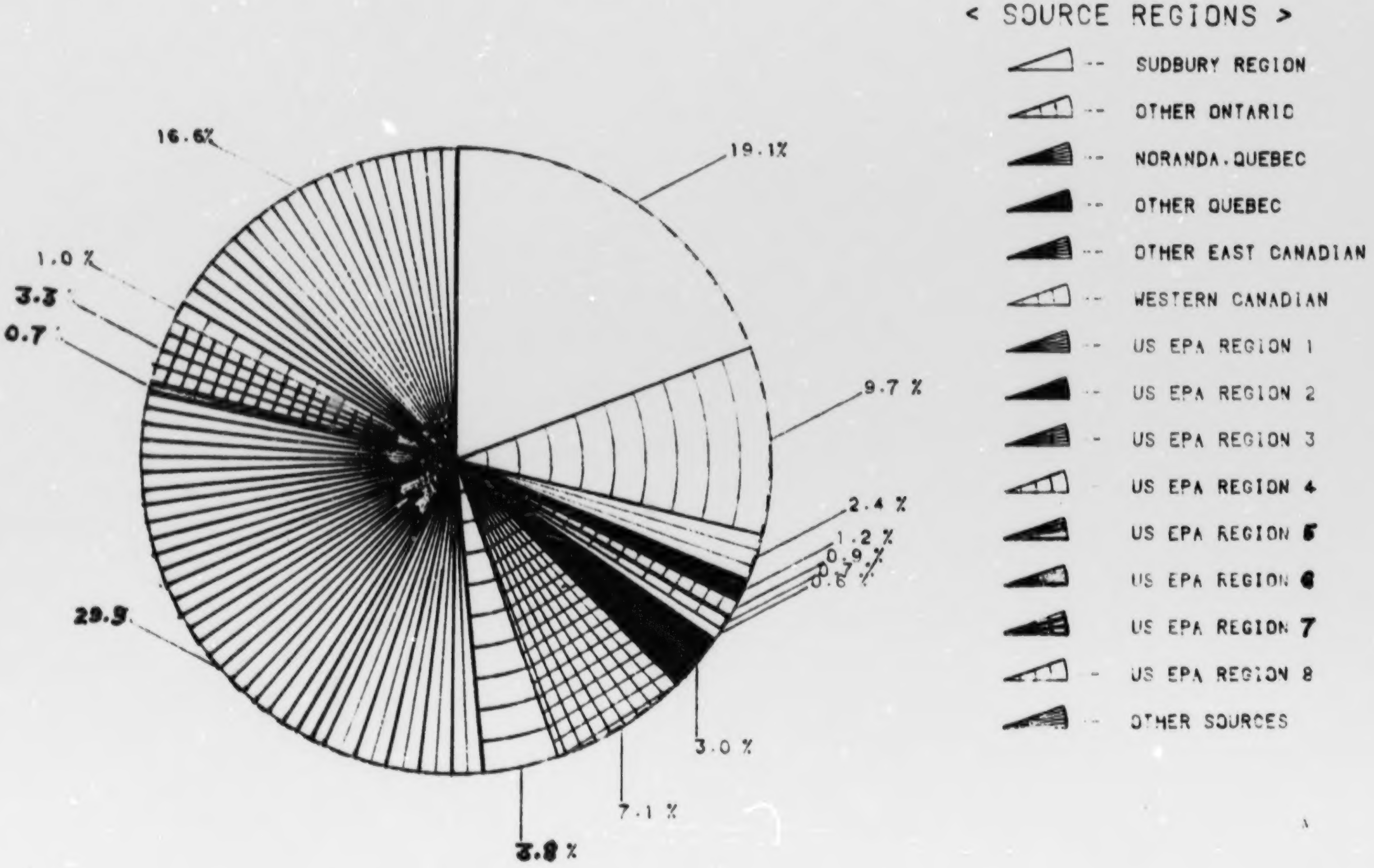


FIGURE 9.7

< PERCENTAGE CONTRIBUTION OF SELECTED REGIONS TO TOTAL SO4 DEP >

RECEPTOR REGIONS : MUSKOKA

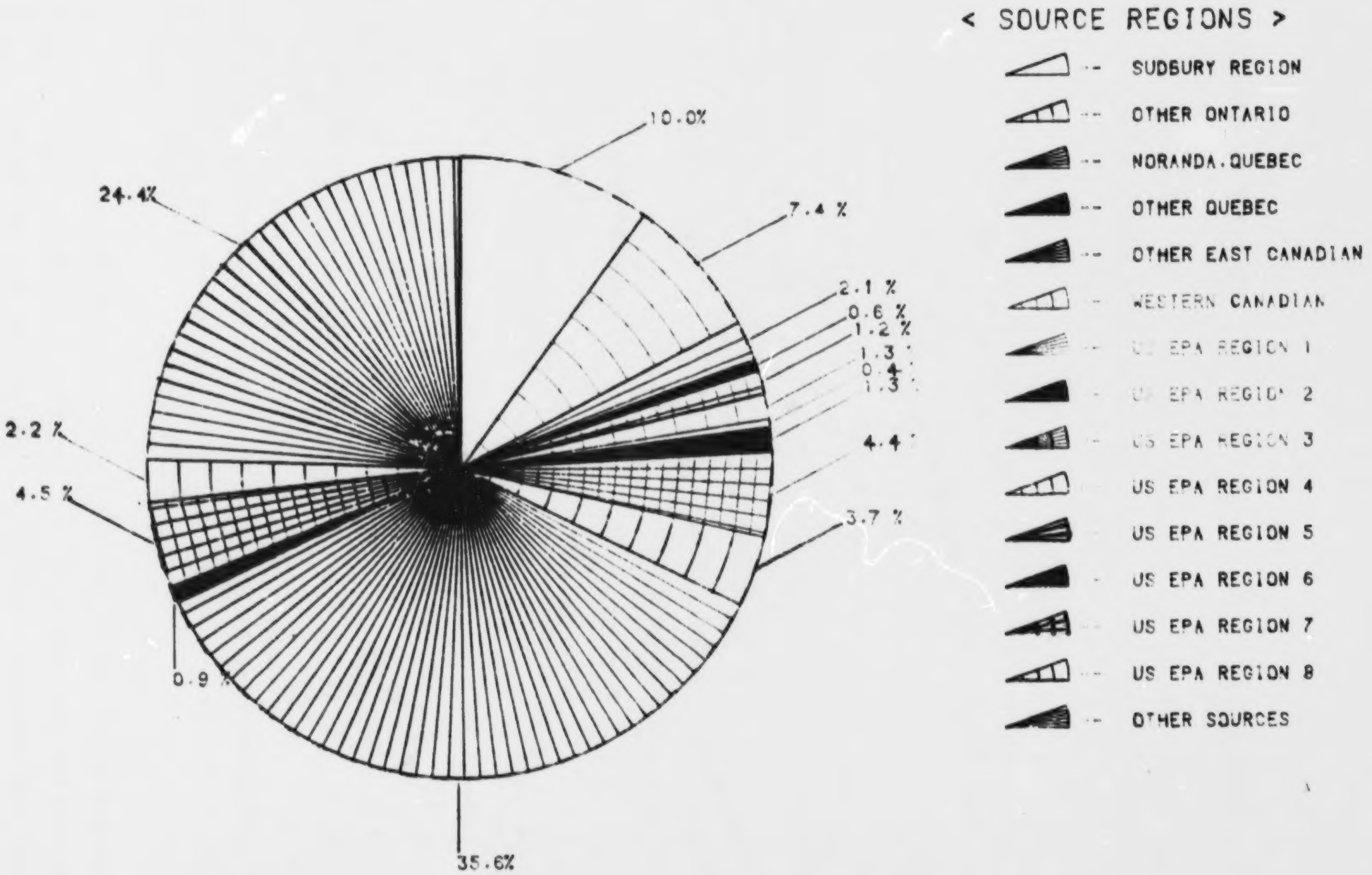


ABSOLUTE DEPOSITION : 37.9
(KG SO4/HA/YR)

FIGURE 9.8

<PERCENTAGE CONTRIBUTION OF SELECTED REGIONS TO TOTAL SO4 DEP >

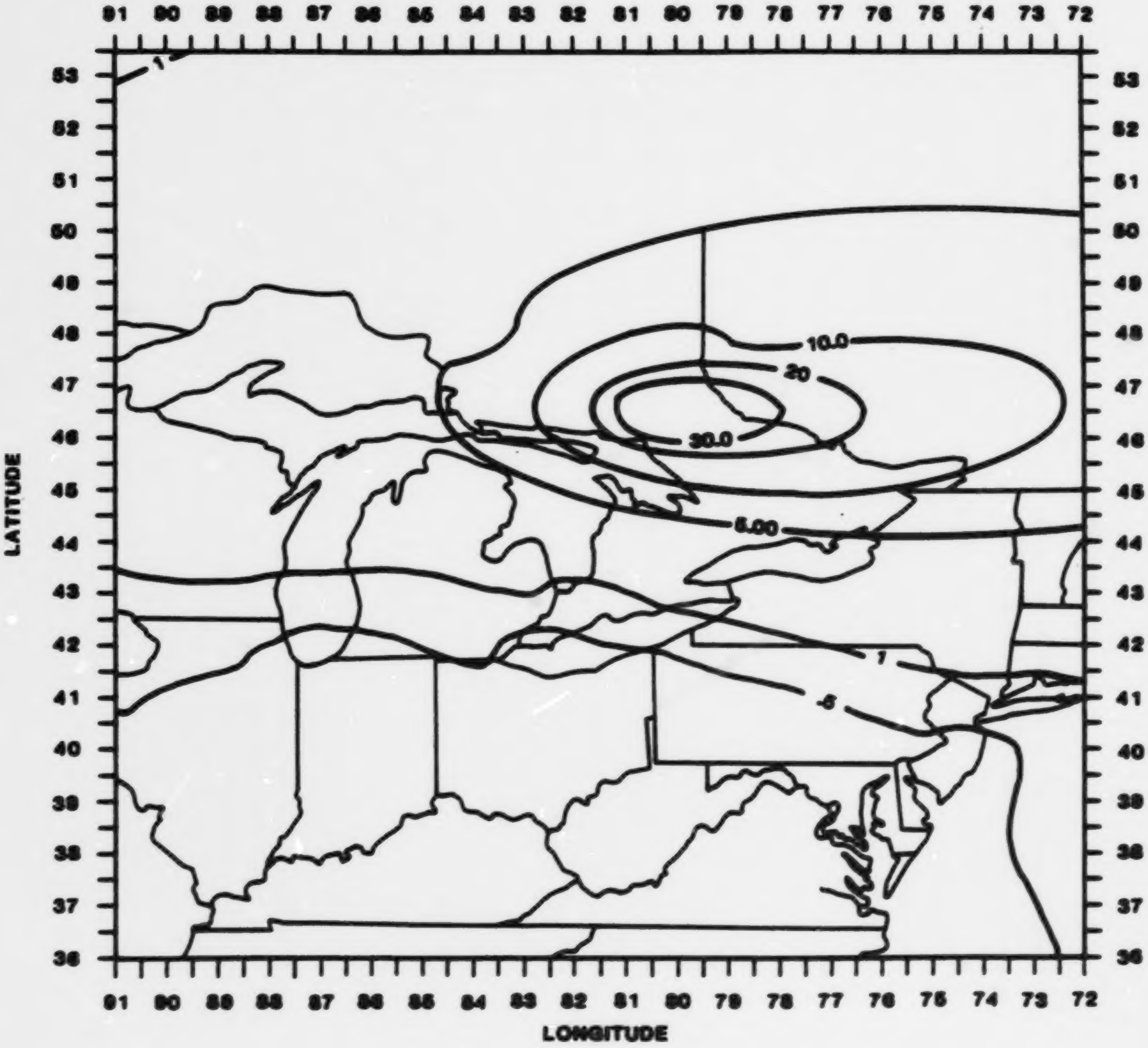
RECEPTOR REGIONS: ALGOMA



ABSOLUTE DEPOSITION . 25.8
(KG SO4/HA/YR)

FIGURE 9.9

CONTOUR MAP OF DEPOSITION OF SULPHUR FROM SUDBURY


91
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74
73
72
53
52
51
50
49
48
47
46
45
44
43
42
41
40
39
38
37
36
LATITUDE
LONGITUDE
1
10.0
20
30.0
5.00
1
.5

Estimated percentage contribution of SO_x sources in the Sudbury region to the wet deposition of sulfur assuming Falconbridge's emissions are the maximum currently allowable and INCO's emissions are the maximum allowable after December 31, 1982, under the August 28, 1980 Control Order.

TABLE 9.1

LIST OF SO_2 CONCENTRATIONS AND AVERAGING PERIODS EQUIVALENT TO A FUMIGATION INTENSITY OF 100

Average SO_2 Concentrations (ppm)	Averaging Period (hours)
0.95	1
0.55	2
0.35	4
0.25	8

TABLE 9.2

MODEL ESTIMATES OF TOTAL (Wet & Dry) DEPOSITION OF SULPHUR (kg SO_4^{2-}/hectare·year) WITH SUDBURY EMISSIONS VARYING FROM 2743 TO 363 TONNES SO_2/DAY

SELECTED RECEPTOR AREAS

SUDBURY Emissions (tonnes SO_2 day	Boundary Waters	Algoma	Muskoka-Haliburton	Quebec City Area	Southern Nova Scotia	New Hamp.	Adirondacks	Western Penn.	Smokies
Base Case (1980)	10.1 (2.5)	23.9 (11.2)	38.1 (19.4)	29.7 (15.9)	34.3 (5.7)	46.0 (9.3)	44.7 (8.0)	111.2 (0.8)	47.7 (0.3)
2721	10.1 (2.5)	23.9 (11.1)	38.1 (19.2)	29.7 (15.8)	34.3 (5.6)	46.0 (9.2)	44.7 (8.0)	111.2 (0.8)	47.7 (0.3)
2268	10.1 (2.1)	23.5 (9.4)	36.9 (16.6)	28.9 (13.5)	33.9 (4.7)	45.3 (7.8)	44.1 (6.7)	111.0 (0.6)	47.7 (0.2)
1814	10.1 (1.7)	23.0 (7.7)	35.6 (13.7)	28.1 (11.1)	33.6 (3.8)	44.6 (6.3)	43.5 (5.5)	110.9 (0.5)	47.7 (0.2)
1361	10.0 (1.3)	22.6 (5.9)	34.4 (10.6)	27.3 (8.6)	33.3 (2.9)	43.9 (4.8)	42.9 (4.2)	110.7 (0.4)	47.6 (0.1)
907	10.0 (0.8)	22.1 (4.0)	33.2 (7.4)	26.5 (5.9)	33.0 (1.9)	43.2 (3.3)	42.3 (2.8)	110.6 (0.3)	47.6 (0.1)
454	9.9 (0.4)	21.7 (2.0)	32.0 (3.8)	25.8 (3.0)	32.6 (1.0)	42.5 (1.7)	41.7 (1.4)	110.5 (0.1)	47.6 (0.05)
363	9.9 (0.3)	21.6 (1.6)	31.7 (3.1)	25.6 (2.4)	32.6 (0.8)	42.4 (1.3)	41.4 (1.1)	110.4 (0.1)	47.6 (0.05)

Notes:

1) The numbers in parentheses are percentage contributions from the Sudbury region to the total (wet and dry) deposition of sulphur.
2) Estimates of total (wet and dry) deposition of sulphur obtained using the long range - long term statistical model developed by the Ontario Ministry of the Environment, for 1980 SO_2 emissions; that year SO_2 emissions from the Sudbury region were about 2743 tonnes per day.
3) The model estimates were found to be within a factor of two of the observed values and over 60% of the model results were within 35% of the expected values.

TABLE 9.3

MODEL ESTIMATES OF PERCENTAGE CONTRIBUTION OF SELECTED SOURCE REGIONS TO TOTAL (wet and dry) SULPHUR DEPOSITION (kg SO_4^{2-}/ha·yr)

Source Region	1980 Emissions (kTonnes SO_2/yr)	SELECTED RECEPTOR AREAS Boundary Waters	Algoma	Muskoka	Quebec City Area	Southern Nova Scotia	New Hampshire	Adirondacks	Pennsylvania	Smokies
Sudbury Region	940.5	1.7	10.0	19.1	14.4	5.5	9.1	7.8	0.8	0.2
Other Ontario Sources	854.0	3.9	7.4	9.7	6.8	5.3	7.2	11.6	3.1	0.4
Noranda, Quebec	566.0	1.0	2.1	2.4	11.4	2.7	3.4	2.1	0.2	0.1
Other Quebec Sources	589.5	0.4	0.6	1.2	10.8	7.2	23.9	4.0	0.2	0.1
Other Eastern Canadian Sources	980.9	5.9	1.2	0.9	2.1	5.2	1.1	0.8	0.2	0.1
Western Canadian Sources	576.6	6.0	1.3	0.7	0.6	0.3	0.4	0.4	0.1	0.1
US EPA Region I	567.8	0.2	0.4	0.6	1.7	10.1	3.0	2.3	.3	0.1
US EPA Region II	1117.3	0.6	1.3	3.0	3.2	8.0	5.7	10.1	2.2	0.4
US EPA Region III	3547.8	2.2	4.4	7.1	6.5	12.2	8.6	12.9	45.5	3.1
US EPA Region IV	5533.3	2.6	3.7	3.8	3.1	4.4	3.2	4.2	4.3	56.5
US EPA Region V	7158.7	14.2	35.6	29.9	15.5	17.1	17.1	25.5	34.0	14.3
US EPA Region VI	1916.7	1.0	0.9	.7	0.6	0.6	0.5	0.6	0.5	4.6
US EPA Region VII	1743.5	3.1	4.5	3.3	1.9	2.0	1.9	2.6	2.4	7.2
US EPA Region VIII	605.8	7.1	2.2	1.0	0.7	0.4	0.5	0.6	0.3	0.5
Other Sources	-	50.1	24.4	16.6	20.7	19.0	14.4	14.5	5.9	12.3
Total	26698.4	100	100	100	100	100	100	100	100	100
Absolute Deposition (kg SO_4^{2-}/ha·yr)		12.6	25.8	37.9	30.2	33.2	43.8	43.6	107.9	51.2

TABLE 9.4

SOME OF THE THRESHOLD LIMIT VALUES CURRENTLY IN FORCE UNDER OHSA AND UNDER CONSIDERATION

Substance	TWA currently in force under OHSA (mg/m^3)	TWAEC under consideration (mg/m^3)
SO_2	13.0 (5 ppm)	5.2 (2 ppm)
Total dust	10.0	10.0
Respirable dust	5.0	5.0
Copper fume (as Cu)	0.2	0.2 copper and its compounds (as Cu)
Copper dusts & mists (as Cu)	1.0	
Nickel oxides and sulphides (as Ni)	1.0	1.0
Nickel, water-soluble compounds (as Ni)	0.1	0.1

10. REVIEW OF THE SOCIO-ECONOMIC EFFECTS

Abstract

Technological or process changes to achieve emission reductions can generate both positive and negative socio-economic effects. The socio-economic impacts of four abatement programs for the Sudbury operations of Inco Limited and seven abatement programs for Falconbridge Limited are presented. These 11 abatement programs represent the expected minimum and maximum socio-economic effects on the Sudbury area.

Based on an historic socio-economic profile of Sudbury, a set of impact variables was selected. These include employment in the various sectors of the Sudbury economy, regional population, wages and salaries, personal disposable income, retail sales, housing demands, school enrollment, consolidated municipal expenditures and consolidated municipal revenues. These impact variables form the baseline conditions to compare the effects associated with the abatement programs. Because of uncertainties regarding population changes in the Sudbury area, especially in light of the current economic situation, 1980 conditions were used as a baseline.

It is also important to point out that the baseline forecasts were developed in the spring of 1982 when the effects of the current recession were not fully apparent. Consequently, in light of recent events in the Sudbury area, notably the shutdown of the smelters and permanent layoffs, the base case projections would appear to be optimistic. Further, if the current conditions persist, the actual baseline scenarios could be about 10% below the conditions presented in this analysis.

It must be stressed, however, that even under a slightly declining scenario, the effects of the abatement programs relative to the base case parameters are less than 3% in all cases. They will, however, worsen the already poor economic conditions in the region.

The abatement programs for Inco Limited are characterized by a major construction phase that will stimulate the local economy. This is followed by a contraction due to both the completion of construction and the reduced labour requirements associated with technological and process changes. Overall, the Inco programs would have a small but noticeable negative effect on the Sudbury area, with impacts representing a decline from 1.3% to 2.2% in the various baseline parameters.

The impacts related to abatement programs for Falconbridge are significantly less than the impacts related to the Inco programs. Relative to the baseline conditions, they would provide a small stimulation to the local economy during the construction phase. Following completion of construction, the impact would initially be a contraction but conditions would still be marginally (less than 1%) above the baseline projections due to increased labour requirements.

10.1 Introduction

Technological or process changes at Inco and Falconbridge in order to achieve emission reductions can produce positive and negative socio-economic effects on Sudbury and the surrounding area. The purpose of this Chapter is to identify the nature, timing and extent of the effects associated with 11 abatement programs. In estimating the effects for each program, the factors considered were the labour force, income, general population, demand for public services and community finance.

The preparation of this socio-economic assessment involves three analytical operations:

- estimating baseline conditions (i.e. the probable future of the Sudbury region without any additional abatement action);
- estimating the probable future of the Sudbury region with different abatement programs;
- comparing abatement programs and baseline projections to provide a measure of change attributable to abatement.

Each of these operations will be briefly discussed in the subsequent Sections.

10.2 Historical and Baseline Development

Baseline projections are estimates of the socio-economic conditions likely to prevail in the Sudbury area if Inco and Falconbridge do not make further emission reductions. The purpose of the baseline forecast is to provide a reference point from which to view the effect of the abatement programs.

In this study, the baseline was developed from an historic socio-economic profile of Sudbury. Based upon an analysis of these historic trends, impact variables were identified and the linkages between these variables and the Sudbury operations of Inco and Falconbridge were determined. The important linkages identified for Sudbury were:

- population growth is historically linked to employment opportunities at Inco and Falconbridge;
- wages and salaries for Inco and Falconbridge have been traditionally higher than the provincial norm, accounting for a level of regional income above the provincial average in Sudbury as a whole;

- retail sales generated are above the provincial average;
- in recent history, the decline in non-ferrous demand, not productivity gains, has reduced the labour forces of both Inco and Falconbridge;
- Sudbury has diversified its employment base of 69,000 with 18,500 employed by Inco and Falconbridge and a similar number employed in the retail/service/trade sectors as of 1980.

These linkages were quantified and combined with the following assumptions which suggest the outlook for the Sudbury area:

- the demographic mix has been traditionally close to the provincial norm and will continue to follow the provincial trend;
- municipal fiscal constraints to bring revenues and expenditures into line will continue and future expenditures will match population (tax base);
- employment levels in the non-mining sectors are largely dependent upon the health of the Ontario economy rather than Inco and Falconbridge.

The current situation has been used as the base from which the impacts of the abatement programs are analysed.

It must be emphasized that these forecasts were developed in the spring of 1982 when the effects of the current recession were not fully apparent. The continued slump in the demand for nickel has forced both Inco and Falconbridge to reduce production and decrease their work force. As of August/September 1982, unemployment estimates in Sudbury have ranged from 26% to 37%. If this situation persists, the actual baseline conditions would be about 10% below those presented in the baseline forecasts. Conversely, if nickel demand and price rises occur during the expected recovery period, the actual baseline conditions could be slightly higher than the situation portrayed in this baseline scenario.

10.3 Abatement Programs and Their Socio-Economic Effects

This Section briefly discusses the socio-economic impacts of four abatement programs for Inco and seven for Falconbridge. (See Table 10.1 for a description of these 11 programs.) A summary of the impacts of these abatement scenarios on Sudbury is presented in Table 10.2. A comparison of these impacts to the baseline forecasts is also provided.

In addition, since the labour force changes attributable to the abatement programs are the driving force behind the socio-economic analysis, the methods and assumptions applied in estimating employment adjustments are highlighted.

The effects of the pollution abatement programs on the Sudbury labour force were considered within the following classifications:

- direct employment created by capital expenditures;
- indirect employment created by capital expenditures;
- direct employment created or lost by technical or process changes;
- indirect employment created or lost by technical or process changes.

Direct labour requirements associated with the implementation of abatement programs are based on a set of factors relating employment to program capital expenditures. Each abatement program is characterized by a capital cost estimate disaggregated into construction and equipment costs. The construction/equipment partitioning is necessary because their labour components are considerably different. The factors used to estimate direct labour requirements are illustrated in Table 10.3.

The direct person years employment created by capital expenditures will have a spinoff for the Sudbury economy. The indirect person years employment generated through construction and equipment expenditures was calculated using an employment multiplier of 1.5. In other words, for each direct person year of employment produced, it is assumed that an additional 0.5 person year of employment is created.

The technological and process changes linked to each abatement program have direct long-term employment implications. In certain cases, the implementation of abatement programs results in an increase in the ongoing labour requirements of Inco and Falconbridge, while in other cases the implementation of more efficient processes results in a net reduction in labour requirements.

Furthermore, these direct employment changes at Inco and Falconbridge will have an effect on employment levels in other sectors of the Sudbury economy. To capture this effect, an employment multiplier of 1.7 was used.

10.4 Socio-Economic Effects

In this Section the potential socio-economic effects associated with the construction and operation of the 11 abatement programs are identified and assessed in terms of their general influence on Sudbury's socio-economic well-being. The effects consist of two distinguishable components:

- the effects over time of the short-term and long-term employment changes associated with the abatement programs;
- the implications of these employment changes on the Sudbury economy and the demand and supply of public services.

The methodology used to forecast these effects is shown in Figure 10.1.

Tables 10.3, 10.4, and 10.5 summarize the likely effects for each of the 11 abatement programs on the socio-economic conditions in the Sudbury area. Table 10.2 shows the projected influence relative to the baseline of each abatement program on employment, income, demand for public services and community finance.

Because the impacts among abatement programs for each firm are small, the results have been combined and expressed to reflect the minimum and maximum potential effects (Tables 10.4 and 10.5).

10.4.1 Inco Abatement Program Impacts

10.4.1.1 Short-Term Impacts

In the short term, all of the Inco abatement programs have positive effects on the Sudbury economy. The construction phase is expected to create between 2,200 and 3,600 person years of direct and indirect employment in the Sudbury area. Depending upon the state of the Sudbury economy and consequently the number and type of unemployed workers in the Sudbury area, the construction phase could generate a short-term in-migration of between 200 and 1,200 persons. These changes will contribute to an improvement in the local economy through additional personal income and increased retail sales.

The new population would lead to an increase in demand for municipal services. The existing public services (i.e. schools, medical and sanitation facilities) have sufficient excess capacity to absorb the new population without reducing the level of services currently provided to local residents.

Concomitant with the increased demand for public services, municipal expenditures are expected to rise slightly ($2 to $3 million) relative to forecast baseline values. Financing these additional demands is not expected to impose any hardships on local residents.

10.4.1.2 Long-Term Impacts

As illustrated in Tables 10.3, 10.4 and 10.5, large differences are projected in the absolute size of the manpower requirements during the construction and operation phases of the four abatement programs. Abatement program Inco 1 ((CCM + RRS) + RWGT + IORP) would have the least negative impact on the Sudbury area in terms of permanent jobs whereas abatement program Inco 2 (OFF) would have the largest negative impact.

When the construction period ends, a net reduction of between 600 and 800 employees at Inco is projected. Including the indirect effects, the total change in the Sudbury labour force from the baseline projection is estimated to be a loss of between 1,000 and 1,400 jobs. These employment losses could produce a maximum decline in population of between 2,600 and 3,400 persons relative to the baseline projections. This represents a decline of between 1.6% and 2.1% of the projected baseline population.

This potential out-migration would influence both the public and private sectors in the Sudbury area. It is estimated that the Inco abatement programs could reduce total aggregate income by $25 to $32 million. This loss represents between 1.8% and 2.1% of the total baseline income.

To provide some insight as to the significance of this potential out-migration, past experience in other centres suggests that as long as the population change represents less than 5% of the area's population, severe socio-economic implications will not be felt.

The reduced income would have several indirect effects on the Sudbury area. Retail sales could decline by $13 to $17 million which represents 1.8% to 2.3% of the 1980 sales. This reduction corresponds to the annual sales of a large supermarket or the sales of 20 to 30 small retail outlets. In other words, the readjustment due to abatement programs could be a major contributing factor to the closing of a number of marginal retail outlets.

In terms of public services, only local educational demands will be affected by the abatement programs. School enrollment is estimated to decline by 500 to 600 students below baseline projections. This level of reduction represents the enrollment of one or two small schools which would employ between 25 and 30 teachers.

In the area of community finance, the local governments in the Sudbury area have been reasonably successful in controlling their spending in response to changing demographic trends. If this practice continues, the municipalities should be able to accommodate the population changes associated with the abatement programs.

10.4.2 Falconbridge Abatement Program Impacts

The impacts ascribed to the Falconbridge abatement programs are significantly less than those associated with Inco (Tables 10.3, 10.4 and 10.5). Permanent employment changes, for example, range from 0.2% to 0.11% relative to baseline projections. Consequently, socio-economic changes would be virtually undetectable at the regional level. For this reason, a more detailed discussion of the expected socio-economic changes with respect to the Falconbridge abatement programs is not provided.

10.5 Conclusions

The purpose of this Chapter was to identify the major socio-economic effects that are likely to occur in Sudbury due to the implementation of various abatement programs at Inco and Falconbridge. The main conclusions of this Chapter are:

- The socio-economic effects associated with the Inco abatement programs are much larger relative to the projected changes associated with the Falconbridge abatement programs. Further, whereas the short-term Inco effects are beneficial, the post-construction employment losses coupled with long-term changes in nickel production technology and market conditions will have a negative effect on the Sudbury economy.

- The maximum net effects from abatement programs for both Inco and Falconbridge would not produce major socio-economic changes to the Sudbury area. They will, however, worsen the poor economic conditions in the community arising from the recent shutdowns and layoffs in the nickel industry. This conclusion is based on two reasons. Firstly, experience in other centres indicates that as long as population change does not exceed 5% of the area population, severe socio-economic implications will

> not occur. The maximum population change associated with an abatement program relative to the baseline is 2.1%. Secondly, even though Sudbury's prosperity is still closely linked to the mining industry, the area has made considerable progress over recent years in diversifying its economy into other sectors. This diversification should act to offset some of the abatement program effects.

Finally, it is important to point out that the maximum impacts associated with any of the abatement programs would be significantly less than the impacts of the current recession.

FIGURE 10.1

ILLUSTRATION OF FORECASTING METHODOLOGY FOR IMPACT VARIABLES

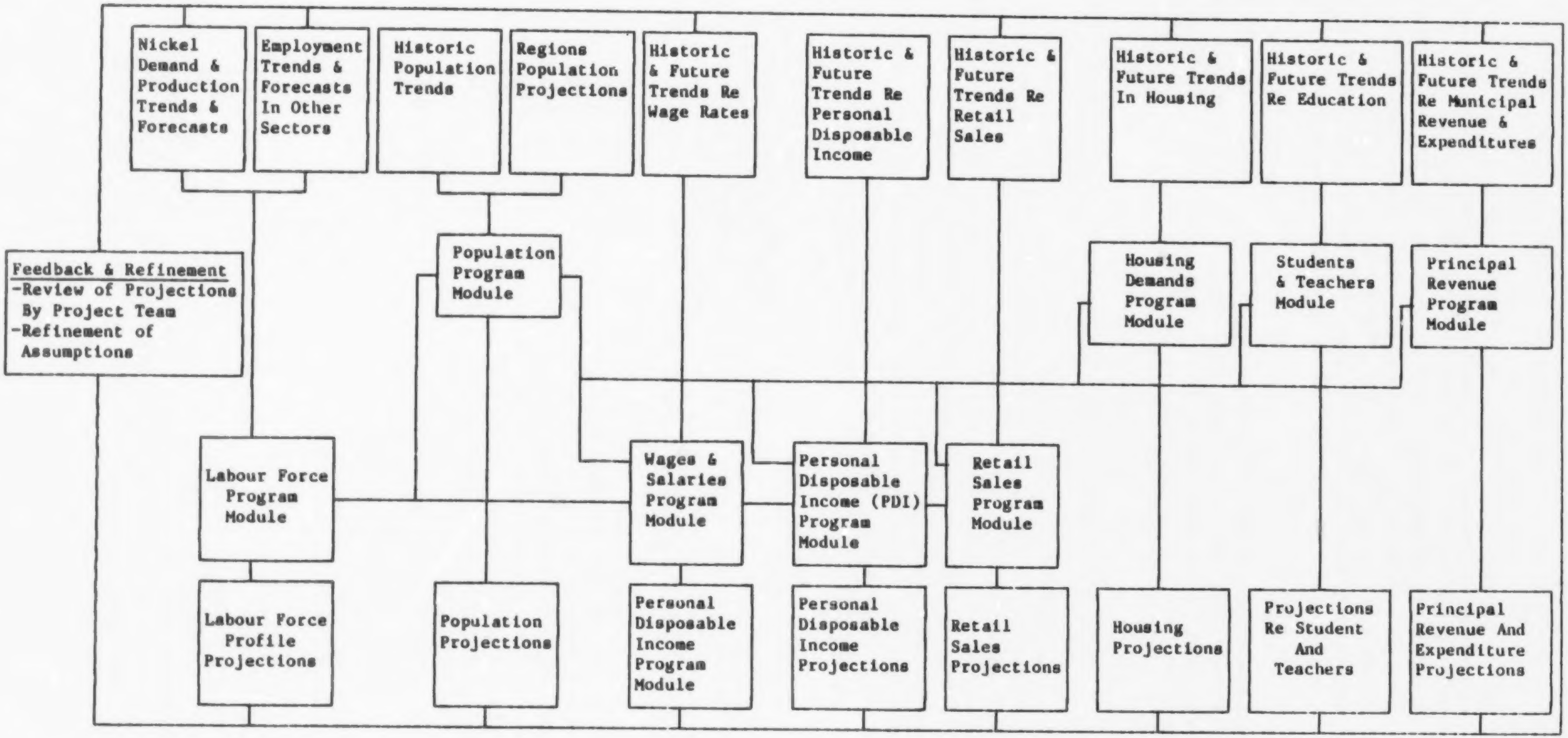
Nickel Demand & Production Trends & Forecasts
Employment Trends & Forecasts In Other Sectors
Historic Population Trends
Regions Population Projections
Historic & Future Trends Re Wage Rates
Historic & Future Trends Re Personal Disposable Income
Historic & Future Trends Re Retail Sales
Historic & Future Trends In Housing
Historic & Future Trends Re Education
Historic & Future Trends Re Municipal Revenue & Expenditures
Feedback & Refinement
-Review of Projections By Project Team
-Refinement of Assumptions
Population Program Module
Housing Demands Program Module
Students & Teachers Module
Principal Revenue Program Module
Labour Force Program Module
Wages & Salaries Program Module
Personal Disposable Income (PDI) Program Module
Retail Sales Program Module
Labour Force Profile Projections
Population Projections
Personal Disposable Income Program Module
Personal Disposable Income Projections
Retail Sales Projections
Housing Projections
Projections Re Student And Teachers
Principal Revenue And Expenditure Projections

TABLE 10.1

GUIDE TO ABATEMENT PROGRAMS USED IN THE SOCIO-ECONOMIC ANALYSIS

Inco

- Inco 1 - Regenerative Copper Circuit, ((CCM + RRS) + RWGT + IORP) Regenerative Roast/Reduction, IORP
- Inco 2 - Nickel Outokumpu Flash Furnace (OFF)
- Inco 3 - Roast/Reduction Smelting (RRS)
- Inco 4 - Inco Alternative (IRRA)

Falconbridge

- Falco 1 - Increased Pyrrhotite Rejection
- Falco 2 - Increased Roast
- Falco 3 - Roast/Reduction Smelting
- Falco 4 - Direct Conversion of Converter Gas to Acid
- Falco 5 - Scrubbing (Regenerative or Non-Regenerative)
- Falco 6 - Increased Pyrrhotite Rejection plus Scrubbing
- Falco 7 - Increased Roast plus Scrubbing

Table 10.2

SUMMARY OF ABATEMENT PROGRAM IMPACTS ON SUDBURY

	Inco 1	Inco 2	Inco 3	Inco 4	Falco 1	Falco 2	Falco 3	Falco 4	Falco 5	Falco 6	Falco 7
Emission Level Achieved tonnes/ SO_2 per day - Ni/Cu Circuit	24	1,120	853	802	267	252	88	143	48	36	44
IORP	19	192	192	92	na	na	na	na	na	na	na
Total Capital Cost ($ million, 1980)	400	225	220	360	2.5	20	38	43	40	42	58
(1982 $)	(475)	(271)	(264)	(430)	(3.0)	(24.8)	(46)	(52)	(48)	(49)	(63)
Construction Period	1983-93	1983-86	1983-90	1983-90	1988-89	1988-89	1988-89	1983-86	1984-85	1985-86	1985-86
Construction Phase Impacts											
Sudbury Direct Employment (Person Years)	2,300	1,700	1,500	2,400	20	150	280	280	260	280	340
Total Sudbury Employment (Person Years)	3,500	2,500	2,200	3,600	30	220	420	420	390	420	540
Total Canadian Direct Employment (Person Years)	5,800	3,700	3,400	5,500	40	330	615	660	610	650	900
Long Term Permanent Transitions											
Inco/Falconbridge Employment Levels (i.e. Jobs Lost or Created)	- 600	- 800	- 775	- 775	+ 70	+ 10	+ 35	+ 30	+ 40	+ 110	+ 50
Sudbury Labour Force Impacts (i.e. Jobs Lost or Created)	- 1,000	- 1,400	- 1,300	- 1,300	+ 120	+ 17	+ 60	+ 50	+ 70	+ 190	+ 85
Sudbury Labour Impacts Force as a % of Baseline Projections 65,000	- 1.59%	- 2.2%	- 2.0%	- 2.0%	+ .18%	+ .03%	+ .09%	+ .08%	+ .11%	+ .29%	+ .13%

Table 10.2 (continued)

SUMMARY OF ABATEMENT PROGRAM IMPACTS ON SUDBURY

	Inco 1	Inco 2	Inco 3	Inco 4	Falco 1	Falco 2	Falco 3	Falco 4	Falco 5	Falco 6	Falco 7
Sudbury Population Impacts (i.e. Out-Migration or In-migration)	- 2,600	- 3,400	- 3,300	- 3,300	+ 300	+ 40	+ 150	+ 125	+ 170	+ 470	+ 210
Sudbury Population Impacts as a % of Baseline Projections (159,000)	- 1.6%	- 2.1%	- 2.1%	- 2.1%	+ .19%	+ .03%	+ .09%	+ .08%	+ .11%	+ .3%	+ .13%
Annual Total Value of Wages and Salaries ($ Million, 1980)	- 25	- 32	- 30	- 30	+ 2.8	+ .40	+ 1.4	+ 1.2	+ 1.6	+ 4.4	+ 2.0
Annual Total Impact Value of Wages and Salaries as a % of Baseline Projections $1534.6 m	- 1.6%	- 2.1%	- 2.0%	- 2.0%	+ .18%	+ .03%	+ .09%	+ .08%	+ .1%	+ .29%	+ .13%
Annual Total Impact Value of Retail Sales ($ Million, 1980)	- 13	- 17	- 16	- 16	+ 1.5	+ .22	+ .75	+ .65	+ .86	+ 2.3	+ 1.1
Annual Total Value of Retail Sales as a % of Baseline Projections $ 1620.6 million	- 1.8%	- 2.3%	- 2.3%	- 2.3%	+ .2%	+ .03%	+ .1%	+ .09%	+ .12%	+ .32%	+ .15%
Annual Total Impact of School Enrollment	- 500	- 670	- 640	- 640	+ 60	+ 8	+ 30	+ 25	+ 30	+ 90	+ 40
Annual Impact School Enrollment as a % of Baseline Projections (37,500)	- 1.3%	- 1.8%	- 1.7%	- 1.7%	+ .16%	+ .02%	+ .08%	+ .07%	+ .08%	+ .24%	+ .11%
Annual Impact Municipal Expenditures ($ x 1000, 1980)	- 2,200	- 2,800	- 2,700	- 2,700	+ 250	+ 35	+ 120	+ 100	+ 140	+ 390	+ 180
Annual Impact Municipal Expenditures as a % of Baseline Projections 126.5 million	- 1.7%	- 2.2%	- 2.1%	- 2.1%	+ .20%	+ .03%	+ .09%	+ .08%	+ .11%	+ .30%	+.14%

TABLE 10.3

EMPLOYMENT PER MILLION DOLLARS (1980) OF CAPITAL EXPENDITURES

CONSTRUCTION EXPENDITURES

SECTOR	PERSON YEARS SUDBURY	PERSON YEARS CANADA	TOTAL PERSON YEARS
Construction	10.6	0.5	11.1
Manufacturing	1.7	7.2	8.9
Transportation & Comm.	1.1	0.8	1.9
Trade	1.1	0.9	2.0
Other	0.5	0.8	1.3
TOTAL	15.0	10.2	25.2

EQUIPMENT EXPENDITURES

SECTOR	PERSON YEARS SUDBURY	PERSON YEARS CANADA	TOTAL PERSON YEARS
Manufacturing	0.50	6.5	7.00
Transportation & Comm.	0.25	1.0	1.25
Trade	0.25	1.5	1.75
Other	0.20	0.8	1.00
TOTAL	1.20	9.8	11.00

TABLE 10.4

PROJECTED MINIMUM AND MAXIMUM EFFECTS OF INCO ABATEMENT PROGRAMS ON SUDBURY

SHORT-TERM EFFECTS (1983-1993)

	Minimum	Maximum
Direct Employment Increases (person years)	1,500	2,400
Indirect Employment Increases (person years)	750	1,200
Total Sudbury Employment Increases (person years)	2,200	3,600

LONG-TERM EFFECTS

	Minimum	Maximum
Inco Employment Losses	600	800
Indirect Employment Losses	420	560
Total Employment Losses	1,000	1,400
Total Value of Wages and Salaries Lost ($ Million 1980)	$ 25	$ 30
Total Value of Lost Retail Sales ($ Million 1980)	$ 13	$ 17
Total Loss of School Enrollment	500	600

TABLE 10.5

PROJECTED MINIMUM AND MAXIMUM EFFECTS OF FALCONBRIDGE ABATEMENT PROGRAMS ON SUDBURY

SHORT-TERM EFFECTS (1983-1993)

	Minimum	Maximum
Direct Employment Increases (person years)	20	390
Indirect Employment Increases (person years)	10	200
Total Sudbury Employment Increases (person years)	30	590

LONG-TERM EFFECTS

	Minimum	Maximum
Falconbridge Employment Increases	10	110
Indirect Employment Increases	7	80
Total Employment Losses	17	190
Total Value of Wages and Salaries ($ Million 1980)	$ .4	$4.4
Total Value of Lost Retail Sales ($ Million 1980)	$ .2	$2.3
Total Loss of School Enrollment	8	90

11. ABATEMENT MECHANISMS AND POLICY CONSIDERATIONS

Abstract

The Task Force has examined the role of the Federal Government in dealing with SO_2 emissions control. It is the belief of the Task Force members that this role should be extended to include not only the long range transport of pollutants across national boundaries, but also the transport of these pollutants across provincial boundaries.

The Province of Ontario currently has effective standards and legislation in effect for controlling single point sources of emissions to mitigate local effects; however, because of the complexity, severity and scope of these effects, additional bolder legislative controls are required to deal comprehensively with all emissions originating from the two Sudbury sources. This new initiative cannot and should not be the responsibility of the Province alone, but rather, should be a cooperative effort between the Federal Government and the Province of Ontario.

11.1 Introduction

In the preceding Chapters, the Task Force has attempted to identify the abatement options available to Inco and Falconbridge for reducing the air pollution emanating from their operations in Sudbury. While these abatement programs are expensive, such expenditures are warranted on the grounds of environmental need with regard to the extent of damage caused over the long term to the environments of Ontario, Canada and elsewhere.

Both of the Companies involved are respected corporate citizens. They have made significant contributions to the Sudbury community, to Ontario and to Canada. Without the abundant bounty of Canada's natural resources, however, neither of these corporations could have achieved their present state of corporate, economic and technical success. The Task Force is hopeful that Inco and Falconbridge will recognize their obligations of corporate citizenry by assuming their responsibility for the timely installation of pollution abatement technology. This sense of cooperation should be guided by enlightened self-interest in addition to public duty. In particular, Inco's nickel smelting facilities give rise to substantial inefficiencies in operation and concurrently cause significant environmental effects. The installation of new and more efficient technology will improve the Company's productivity as well as environmental quality.

All Canadians hold the lands, lakes, air and forests of this nation in trust for future generations. Accordingly, there is an obligation upon all levels of government to guarantee that the necessary mechanisms exist to ensure a habitable and useful environment. The Task Force's terms of reference instruct its members to evaluate the consequences of government policies intended to "induce abatement by the Companies". Therefore, it is necessary to evaluate the existing regulatory regime in order to ensure that it is capable of inducing effective abatement by the Companies.

By discharging pollutants into the environment, the Companies have passed on to others the costs of the environmental damage resulting from their smelters. The principle that the polluter should pay suggests that the Companies should bear these costs. Due to their low production costs, the opportunity exists for Inco and Falconbridge to internalize some of these costs through pollution abatement.

11.2 The Federal Government's Role in Controlling Emissions

The Sudbury sources emit contaminants which have both a local and a long range impact, causing harm within the Province of Ontario as well as within other Canadian provinces and some American states. An effective statutory regime requires cooperation and action by both the Federal Government and the Province of Ontario to curtail emissions and also to deal with rehabilitation of the affected areas. When the environmental effects occur within Ontario's boundaries, the Province clearly has jurisdiction over controlling the sources, but when the effects are interprovincial in nature, then, the Federal Government should assume responsibility.

For its authority in this area, the Federal Government relies primarily on the Clean Air Act of 1971. In particular, the Federal Government may establish national emission standards when such emissions "constitute a significant danger to the health of persons". While acidic precipitation is a serious environmental problem, current evidence does not support the conclusion that present emissions constitute a "significant danger to the health of persons". Based on the evidence currently available, it is unlikely, therefore, that national emission standards controlling sources and pollutants causing acidic precipitation will be enacted.

In 1980, the Clean Air Act was amended to deal specifically with questions of international pollution. Under this amendment, Parliament can enact emission standards where emissions constitute "a significant danger to the health, safety or welfare of persons" in a country other than Canada. The important difference between the basis for the enactment of emissions standards in these two situations is that, on an international level, when such emissions endanger the safety and (human) welfare, in addition to (human) health, which is the sole basis for action on a national level, the Federal Minister of the Environment can enforce the legislation. Thus, insofar as health effects in Canada remain unproven, there is little reason for federal action. However, to the extent, that emissions from Sudbury may constitute a significant danger to the health, safety or welfare of persons in the United States, the Federal Minister of the Environment could impose emission standards aimed at eliminating or reducing that danger. The term "welfare", while not defined in the Act, can be deemed to include the natural environment based on the definition for air pollution (contained in Section 2 of the Act), where welfare includes "normal enjoyment of life or property, that endangers the health of animal life, or that causes damage to plant life or to property".

Present Federal legislation does not provide the basis for regulation of interprovincial pollution, such as acidic precipitation, causing environmental damage. It can, however, be strengthened to deal with the serious issue of interprovincial air pollution since the present constitutional division of powers does not contemplate Provincial Legislation enacted for the sole purpose of protecting the environment of a neighbouring province. The latter responsibility would appear to be uniquely a federal one and consideration must be given to the implementation of amending legislation intended to strengthen the federal role in the prevention of interprovincial air pollution and the rehabilitation of the environment harmed by such pollution.

In summary, the Federal Government will continue to play a limited role in controlling emission discharges from Inco and Falconbridge under current legislation. However, the Federal Government's role should be extended to provide for the regulation of interprovincial air pollution. This expansion of the federal role would reflect the commitment by the Federal Government to the effective control of emissions causing acidic precipitation. The current legislation could be amended to provide this ability to the Federal Minister of the Environment and the Task Force urges that this opportunity be explored and developed further. This would provide the Federal Crown with a statutory basis from which it can assist in controlling Canadian sources of "acid rain".

11.3 The Role of the Province of Ontario in Controlling Emissions

The Ontario legislative enactment intended to regulate air emissions is the Environmental Protection Act, 1971. This Act specifically provides protection for the natural environment of the Province of Ontario which includes the air, land and water of the province. The Environmental Protection Act governs the discharge of particulate matter as well as the discharge of SO_2. The legislation is of general application throughout the province without particular distinction for regional or localized problems. The Act can be used to penalize polluters guilty of large and serious environmental damage and has proven to be effective when dealing with localized and contained problems in which the burden of establishing causality of harm can be easily met by the prosecution. Both Inco and Falconbridge have been convicted of environmental offences relating to their Sudbury operations. To date, the cost to the public of such prosecutions has far exceeded the fines imposed and the deterrent factor of such prosecutions is open to grave doubt.

The operations of Inco and Falconbridge in Sudbury present problems of outstanding technological complexity. Technical options for abatement are sophisticated and expensive. Just as there are no easy technical answers to the problems encountered in Sudbury, so there are no easy regulatory or legislative answers to the same problems. While the Environmental Protection Act would appear to provide an effective legislative remedy for controlling Sudbury's emissions, upon closer examination, one must acknowledge the frailty of the systems when confronted with a problem of Sudbury's magnitude. The requirement of strict proof of the causality of harm is imposed upon the prosecutor and the taxpayer who supports him. As indicated previously, the cost to the public of previous prosecutions of Inco and Falconbridge far exceeded the amounts of the fines imposed upon successful conviction. Further, it is highly unlikely that the quantum of fines that could be imposed would approach the savings accruing to the Company by evading abatement. Even if the daily maximum fine were substantially increased, it would still be small relative to the high costs of the abatement options discussed and thus, would not likely serve as an incentive to abate.

In other words, a fine is less of a deterrent when the cost of abatement is known and the value of damage is indeterminate.

The Task Force does not propose changes to the Environmental Protection Act. It is valid and effective legislation for dealing with many of this province's environmental problems. However, the emissions in Sudbury are unique in terms of their complexity, severity and scope of damage. Therefore, these emissions require additional legislative controls intended to deal comprehensively with all emissions originating from the two Sudbury sources.

The Environmental Protection Act has been inadequate to deal effectively with the complex Sudbury environmental problem in the past, especially in the case of fugitive emissions from Inco and Falconbridge. Legislation should be enacted which comprehensively tackles all emissions from Inco and Falconbridge and which eliminates the necessity of attributing emissions to a specific source within their operations. The present cost of monitoring emissions from particular production point sources places an undue financial burden upon the taxpayer. The cost of prosecution for offences relating to specific discharge points, as opposed to the entire operation being considered as one discharge point, has resulted in fines which do not approximate the cost of the prosecution let alone the cost of the environmental damage. Finally, the Task Force is not convinced of the efficacy of punitive fines as a measure intended to induce abatement by these Companies, where the cost of abatement is twenty thousand times the amount of the highest fine imposed to date.

11.4 An Interim Solution

Pursuant to Section 14 of the Environmental Protection Act, the prohibitions therein contained set out the maximum allowable ground level concentrations of emissions at point of impingement, not the maximum standard permissible, and empower the Lieutenant-Governor In Council to make further regulations imposing new restrictions. While the Act itself does not address specific source emissions, the Lieutenant-Governor In Council has in the past (September 2, 1980) expressly limited sulphur dioxide emissions from Inco's operation at the Copper Cliff smelter. Similar regulations have been applied to control emissions of sulphur dioxide and nitrogen oxide from Ontario Hydro.

Therefore, until new and comprehensive legislation is enacted to deal with the particular environmental problems resulting from the total emissions of Inco and Falconbridge, it is believed that implementation of an interim pollution abatement program should be dependent primarily upon a series of specific regulations detailing the permissible levels of emissions from particular sources in the context of a predetermined timetable. This would be a continuation of recent practice, but it is probable that a new legislative initiative will eventually make this regulatory approach unnecessary.

In its evaluation of possible implementation mechanisms, the Task Force also gave due consideration to the use of the control order. However, due to the complexity of the technical options, the extended time period in which implementation would take place and the inherent potential for delay, it was concluded that this mechanism is not appropriate for the task at hand.

11.5 Longer Term Options

In the short term, it is believed that the best available mechanism for assuring implementation is the power of the Lieutenant-Governor In Council to pass the necessary regulations, however, over the longer term, newer and bolder legislative initiatives are required to deal with the problems of Sudbury emissions. The Task Force considers that phased reductions of emissions would likely constitute the most practical, effective and equitable way to proceed.

Such phased reductions would entail a complex series of interrelated regulations, one following and dependent upon the other. Further, the Sudbury smelters emit different types of contaminants, each of which would require a series of regulations intended to deal with the problems associated with that particular contaminant. There is the possibility that such a complex series of regulations could fail to deal with all of the problems presented by Inco and Falconbridge and would certainly not deal with those problems in an entirely systematic and comprehensive manner.

Therefore, the legal profession is currently presented with a unique opportunity to consider new methods for insuring compliance with environmental legislation. Among the legislative options which should be considered, is the option of economic incentives, to include, specifically, emission charges. While this Task Force does not consider it part of its mandate to formulate and propose specific new legislation, it does believe that Inco and Falconbridge ought to have imposed upon them the necessary economic incentives to achieve a predetermined environmental standard. On the other hand, failure to meet the predetermined environmental standard must result in a charge per unit of pollution which will remove any economic disincentive which might accrue to the Companies by delaying implementation of the required pollution abatement program.

Any contemplated legislation should deal with the rehabilitation of those areas damaged by emissions. The emission charges levied against the Companies, therefore, will both discourage future emissions and repair damage.

The Task Force realizes that any suggestion that new legislation be contemplated, in particular legislation which bears a novel and distinct focus from any previously employed in Canada and in Ontario, will be subject to doubt and skepticism from many quarters. However, resorting only to the powers of the Lieutenant-Governor In Council to pass an ever increasing number of complex regulations ultimately will prove to be of only marginal utility. A new legislative thrust which seeks to remove the economic incentive to delay compliance and which seeks to create an impetus for technical advancement must be considered. Particularly, in this case where the emissions originate from within a clearly defined geographical area, the proposed legislation should deal with all emissions from all sources within that area.

This new legislative initiative cannot and should not be the sole responsibility of the Province of Ontario. Having regard to the interprovincial and international aspects of the problem, the Government of Canada must assume its rightful share of this task, including the implementation of complementary legislation and standards.

The Task Force acknowledges that, because of the current economic situation and each firm's financial plight, it may be several years before either Company is able to finance a major emission abatement program by internal cash flow, new equity issues, increased debt or by a combination of these methods.

The Task Force urges that consideration be given to traditional forms of assistance which could include accelerated depreciation of capital costs associated with the installation of pollution abatement equipment, the waiver of applicable sales and excise taxes, loans, loan guarantees and grants. Given the proposed cost of the technical options reviewed, it is unlikely that any or all of these particular types of financial assistance alone will effectively "induce abatement" without the backing of strong, unequivocal and comprehensive legislation.

GLOSSARY OF TERMS

acid:	a substance capable of donating a proton (H+); on a pH scale of 0 to 14, substances with a pH less than 7.0 are acidic (e.g. vinegar and orange juice)
acidic:	having the properties of an acid
acute vegetation injury:	visible injury which is caused by exposure to high concentrations of SO_2 during short time periods
alloy:	a substance that is a mixture, as by fusion, of two or more metals or of a metal and something else
amortize:	to write off (expenditures) by prorating over a fixed period
anthropogenic:	arising as a result of man's activity; a term applied to emissions of pollutants (ex. anthropogenic sources vs. natural sources)
assaying:	the process whereby an ore or alloy is analysed to determine the nature, proportion, or purity of the ingredients
background level:	a concentration of material(s) in air or water arising from other than anthropogenic sources; a level likely to be encountered in the vicinity of the source of contamination if the source were not present
Bessemer matte:	a matte which is 77% nickel/copper/cobalt and low in iron and sulphur
biomass:	the total amount of living organisms in a particular area
biosphere:	the zone of the earth, extending from its surface out into the surrounding atmosphere, which contains living organisms; all the living organisms of the earth
blast furnace:	a towerlike furnace for separating metal(s) from the impurities in the ore
blast furnace smelting:	the process whereby metal is separated from the impurities in the ore using a blast furnace

blister copper:	copper that is 96 to 99 percent pure, produced by smelting; it has a blistery surface caused by sulphur dioxide bubbles
briquetting:	process whereby ore particles are formed into briquettes
buffer:	to stabilize the hydrogen ion concentration in a solution by neutralizing any added acid
buffering capacity:	the capacity of a solution to maintain the concentration of hydrogen ions within a given range
bulk deposition:	comprises both wet deposition and a fraction of the particulate and gaseous material which reaches the earth's surface by dry deposition
calcine:	product of roasting
calibrated watershed:	a selected water drainage area, for which the total inflow and outflow can be measured and the concentrations of materials determined
capital costs:	money needed to be spent in order to replace, expand or improve a plant or process facilities, not including operating costs required to keep facilities working
capital expenditure(s):	money spent to meet capital costs
catalyst:	a substance that speeds up or, sometimes, slows down the rate of a chemical reaction without undergoing any permanent chemical change itself
chalcopyrite:	a yellow sulphide of copper and iron
chemical weathering:	the wearing away, damaging, discolouring or other deleterious effects on materials or the environment under the influence of chemicals present in the atmosphere

chronic vegetation injury:	chlorotic foliar damage (as well as reductions in other growth factors) caused by exposure to variable SO_2 concentrations over long time periods
Clean Air Act:	the Canadian government act enabling the development and enforcement of regulations governing sources of pollutant emissions
complexation: (complexing)	a process by which a reactant molecule is enclosed with a larger molecule and its interaction with the surroundings is inhibited; thus, it is effectively prevented from reacting with other substances in its normal manner
concentrate:	(in metallurgy) an extract of an ore into which the principal metal of concern has been concentrated
concentrator:	the plant in which a concentrate is produced
control order:	an order issued by a Ministry of the Environment Director to a person/source to reduce the level of contaminants emitted to that level prescribed by the regulations
converter:	equipment in which converting is carried out
converting:	the process of treating a nickel/copper/ iron/sulphur melt in order to eliminate more of the unwanted components, thereby putting the valuable metals into (i.e. converting) a form better suited to their recovery
copper circuit:	part of the smelting process where iron and sulphur are removed from the copper concentrate
copper converter:	a converter used for the production of copper
copper flash furnace:	a flash furnace used for the production of copper matte in which a copper sulphide ore concentrate is flash smelted by the burning of some of its sulphur and iron content while it is suspended in an oxidizing atmosphere; see also flash furnace and flash smelting

cost effective program:	that program which yields the highest profit contribution or the lowest cost for a given abatement level
deposition rate:	the mass of deposition per unit area per unit time, usually expressed as kg/hectare·year
deposition velocity:	a hypothetical average rate of fall of deposited material; used to estimate deposition rates in situations where they cannot be measured
dilute gas streams:	gas streams carrying sulphur dioxide in concentrations unsuitable for the direct production of sulphuric acid, generally less than 4% by volume
dispersion:	the reduction in concentration of an emitted substance as it travels and mixes in the atmosphere
dry deposition:	the process by which particulates, such as fly ash, or gases, such as sulphur dioxide or nitric oxide, are deposited or adsorbed onto surfaces without the intervention of precipitation
economic viability:	in reference to an abatement program, its ability to yield a sufficiently large return on invested capital to compensate the providers of that capital
electric furnace smelting:	smelting process carried out in a furnace in which heat for the smelting is supplied from electrical energy
electrostatic precipitator:	a device for removing particulates from industrial emissions (often removal efficiencies of greater than 95% can be realized with these devices)
elemental sulphur:	sulphur in an uncombined form
elemental sulphur recovery:	process in which elemental sulphur is obtained from waste materials, often from waste sulphur dioxide
financial attractiveness:	see economic viability
fixation:	the reduction of a substance into a solid or nonvolatile form

flash furnace:	a furnace used to smelt sulphide ore concentrate by burning some of the sulphur and iron content while the concentrate is suspended in the oxidizing medium, in much the same manner that pulverized coal is burned; the concentrate and a flux material (e.g. silica sand) are injected in this furnace with oxygen or preheated air, and the smelting temperature is obtained by the 'flash' combustion of the iron and sulphur; the concentrate is made to roast and smelt itself in a single operation
flash smelting:	a smelting process carried out in a flash furnace
flotation:	a method of ore separation in which finely powdered ore is introduced into a bubbling solution to which oils are added: certain minerals float on the surface and others sink
flue:	a tube, pipe, or shaft for the passage of smoke, hot air, gas, etc.
fluid bed roaster:	a chamber, usually of circular cross-section, in which roasting is accomplished with grate hearths through which oxygen-bearing gas, usually air, is blown; as the material to be roasted is fed to the chamber, air is blown through the grate at a rate sufficient to hold the solid particles in suspension while roasting occurs; the mixture of air and solids has the flow characteristics of a fluid
fugitive emissions:	uncontained emissions which escape directly into the atmosphere without passing through ducts or chimneys
fumigations:	conditions whereby high concentrations of pollutants are brought to ground level as a result of atmospheric turbulence, usually following from the breakdown of an atmospheric inversion system
gangue:	the commercially worthless mineral matter associated with economically valuable metallic minerals in a deposit

green ore:	ore as it is brought from the mine; prior to treatment
ground level concentrations:	concentration of an atmospheric contaminant as measured or calculated at ground level
hearth:	the lowest part of a blast furnace on which the molten metal and slag are deposited; the floor of a furnace on which the ore or metal rests above the flame
hourly average:	average of a number of measurements made during one hour; alternatively, a measurement made upon a single sample taken during the course of one hour
hydrometallurgy:	the recovery of metals from ores by a liquid process, as by leaching the ore with an acid
interstitial water:	water found in the spaces between particles of soil or between cells of an animal
invertebrates:	animals having no backbone or spinal column
laterite:	a red, residual soil containing large amounts of aluminum and ferric hydroxides, formed by the decomposition of many kinds of rocks, and found especially in well drained tropical rain forests
leachate:	liquid that has filtered through a solid, dissolving part of it in the process
leaching:	pertaining to the losses of soluble matter as a result of the filtering through of water; dissolving and being washed away
long range transport:	the transfer of air contaminants over long distances (i.e. hundreds of miles) by the movement of the air in which they are dispersed
magnetite:	a black iron oxide
matte:	a mixture of sulphides, copper, nickel and iron which results from fusion and partial oxidation of the concentrate

metallurgy:	the science of metals, especially of separating metals from their ores
metal particulates:	particulate matter containing metals in the elemental or combined states
microclimatic:	characterized by having the climate of a small distinct area
microequivalent:	unit of measure equal to one millionth of an equivalent (an equivalent is a chemical unit which is the quantity by weight of a substance that combines with one gram of hydrogen)
microgram:	a unit of weight equal to one millionth of a gram (a gram is the basic unit of measurement in the metric system, equal to approximately 1/28 of an ounce)
microorganism:	any animal or vegetable organism visible only through a microscope
middlings:	nickel/copper concentrate recovered from pyrrhotite-rich fractions with recoverable copper and nickel still present
mill:	a building or group of buildings housing machinery for processing
milling:	stage in the production process whereby crushed ore is received from various mines in the area and through further processing (ore concentration), the unwanted materials are rejected and the sulphide minerals are separated from one another
mineral dressing:	a process whereby an ore is crushed or ground in order to liberate the valuable materials from the unwanted material which is then discarded
mobilization:	(of metals) process whereby metals are released from solution, lake sediments or soils, due to chemical interactions

monitoring network:	a number of collection devices (samplers) distributed over a large area designed to collect samples of rain/snow (sometimes dry matter) with the objective of determining the acidity or composition of precipitation over long time periods
multi-hearth roaster:	a roaster, often called a Herreschof roaster, in which a series of hearths are arranged vertically in a single vessel in such a way that the solid materials pass from hearth to hearth in a downwards direction while gases pass upwards in counter current flow
neutralization:	mixing of acidic and alkaline materials so as to produce a pH close to 7.0; process whereby an alkaline substance is added to the aquatic or terrestrial ecosystem in order to increase its buffering capacity
nickel circuit:	part of the smelting process where iron and sulphur are removed from the nickel concentrate
nickel converter:	a converter used for the production of nickel
nickel flash furnace:	a flash furnace used for the production of nickel matte in which a nickel sulphide ore concentrate is flash smelted by the burning of some of its sulphur and iron content while it is suspended in an oxidizing atmosphere: see also flash furnace and flash smelting
nickel ore:	a naturally occurring combination of nickel-bearing minerals
non-ferrous:	not made of or not containing iron
oligotrophic:	designating a pond or lake, etc. poor in plant nutrient minerals and organisms and rich in oxygen at all depths
open heap roasting:	roasting accomplished by piling concentrate into large heaps and igniting the pile

operating costs:	costs incurred in operating a plant or process, including costs for labour, maintenance, overhead, chemicals, fuel, water, waste disposal, etc.
option:	process change or major modification
ore concentrate:	a material produced from an ore after a major part of the gangue (invaluable material) has been removed
ore concentration:	a two stage process whereby first the metallic sulphide minerals are separated from the gangue (waste rock) and then the nickel sulphides, copper sulphides and pyrrhotite (iron sulphide) are separated from each other
overburden:	soil, rock or other naturally occurring material overlaying a useful deposit
oxidation:	a reaction in which substances combine with oxygen
oxygen flash furnace:	a flash furnace in which oxygen is the combusting agent
oxygen plant:	a plant for producing oxygen from air
particulate(s):	pertaining to or consisting of small separate particles often used as an abbreviation of "particulate matter"
particulate emissions:	emissions characterized by being made of small particles
particulate matter:	matter in the form of small particles
pentlandite:	the principal ore of nickel
pH:	a logarithmic measure of the hydrogen ion concentration on a scale ranging from 0 to 14; used to gauge the acidity or alkalinity of a solution
phytoplankton:	plankton consisting of plants, as algae
pilot plant:	a small scale plant where a process is tested, usually about ten to one hundred times as large as equipment used in the laboratory

plankton:	microscopic animal or plant life usually found floating/drifting in bodies of water
podzolic (soil):	refers to a major soil type of northern regions, characterized by a strongly acid, infertile humus underlying a thin mat of leaves and decaying vegetation
point of impingement:	point at the ground or at an object contacted by a plume from a stack; sometimes used to identify the point of contact where maximum concentrations occur
point source:	an emission source where contaminants are emitted through a stack; different from area source
potentially injurious fumigations:	exposures to emissions of high concentrations of fumes that could potentially result in injury to plant life; usually caused by a fumigation event
program:	a number of options, both process and abatement, in combination
public services:	services supported/financed by public (government) funds
pyrometallurgy:	the recovery of metal from ores using high temperatures as in roasting or smelting
pyrrhotite:	any of several magnetic, bronze-coloured, lustrous native sulphides of iron, often containing small amounts of copper, cobalt and nickel
pyrrhotite rejection:	rejection/discarding of separated pyrrhotite to a degree beyond that carried out previously
pyrrhotite removal:	removal of the separated (relatively invaluable) mineral pyrrhotite from the nickel ore concentrate
pyrrhotite separation:	separation of a quantity of the mineral pyrrhotite from the nickel ore concentrate
pyrrhotite treatment plant:	plant where the mineral pyrrhotite is converted to iron oxide and any nickel in the pyrrhotite may be recovered

reduction:	a reaction in which oxygen is removed: see oxidation
refinery:	the area where the quality of the nickel produced in the smelter is upgraded by further treatment to produce a metal of high purity
refining:	a process whereby impurities are removed from a concentrate
reverberatory furnace:	furnace or kiln in which ore, metal, etc. is heated by a flame deflected downward from the roof
roasting:	operation whereby sulphide ores are heated in air in order to reduce their sulphur content while converting some of the metals, primarily iron, to their oxides so that they may be removed in the slag; sometimes the sulphur dioxide produced is used to make sulphuric acid
roasting/ briquetting:	a process in which the product of roasting (i.e. calcine) is shaped into briquets (or pellets)
roast/reduction:	a roasting/smelting process carried out in the presence of coke which serves to limit the extent to which the metals are converted to metallic oxides and to reduce their losses in the slag
roast yard:	an area where roasting is undertaken
scavenging:	a process whereby molten metal is cleaned by using a substance that will combine chemically with the impurities present
scrubbing:	process whereby a gas is cleansed of impurities
sedimentation rate:	the rate at which particles settle to the bottom of a lake or pool of liquid
single point source:	an emission source where all emissions are discharged through one stack

sintering:	process whereby an ore in a fine dust form is fused by heating in order to produce large pellets of a porous nature
slag:	a melt which contains most of the unwanted constituents originally in the nickel/copper ore concentrate rendered liquid by the addition of fluids which combine with the impurities and thereby reduce their melting points
slag cleaning:	a process used to recover valuable metals which have been removed from the main process stream by dissolution in the slag
smelter:	a factory in which metallurgical operations, including smelting, are carried out
smelting:	melting of ore concentrates by thermal treatment and the bringing about of physical chemical changes that enable recovery of desirable metals (eg. nickel or copper) in crude form, separated from the bulk of unwanted constituents
spring pulse:	shock loading of acid to streams and to the surface waters of lakes which occurs when the hydrogen ions (acid) stored in the snow are released in a short time period during runoff in the spring thaw
statistical model:	simulates long-term deposition and is designed to establish source-receptor relationships resulting from the transport of contaminants over distances of hundreds of kilometers
strong gas stream:	gas stream containing greater than 4% sulphur dioxide by volume
strong off-gas:	an off-gas with a relatively high concentration of a constituent, eg. sulphur dioxide, usually for sulphur dioxide greater than 4% by volume above which the direct production of sulphuric acid is considered to be feasible
sulphate:	a compound of sulphur and oxygen in combination with a metal such as sodium or calcium; a sulphate is formed by reaction between sulphuric acid and a metal oxide

sulphur:	a pale yellow non-metallic element which burns to produce sulphur dioxide
sulphur dioxide:	a compound of sulphur and oxygen produced when sulphur or a metallic sulphide is burnt in air
sulphur dioxide concentrations:	the amount (volume) of sulphur dioxide in a unit volume of a mixture of gases
sulphur dioxide containment:	the collection of sulphur dioxide from a gas stream, rather than permitting its escape to the atmosphere
sulphur fixation:	the conversion of sulphur dioxide to a state or to a compound by which it can be prevented from escaping into the atmosphere
sulphuric acid:	a highly corrosive acid formed from the combination of sulphur dioxide and water
sulphuric acid manufacture:	the production of sulphuric acid, usually by the formation of sulphur trioxide from sulphur or sulphur dioxide and its subsequent dissolution in water
synergistic effects:	the simultaneous effects produced by separate contaminants which in combination have a greater total effect than the sum of their individual effects
tail gas:	the sulphur dioxide not captured
tailings:	waste or refuse left in various processes of milling, mining, etc.
ton:	a unit of weight equal to 2,000 pounds
tonne:	a metric unit of weight equal to 1,000 kilograms, or approximately 2,200 pounds
total deposition:	the total of dry and wet (in precipitation) depositions
troy ounce:	unit of weight used for gold, silver, precious stones; equal to 31.1 grams
weak gas stream:	gas stream containing less than 4% sulphur dioxide by volume
weak gas treatment:	sulphur dioxide removal from off-gas containing a low concentration, less than 4% by volume, of sulphur dioxide

weak off-gas:	gas discharged from a process and having a low concentration of sulphur dioxide (less than 4% by volume)
wet deposition:	the process by which particles or gases such as sulphur dioxide or nitric oxide are deposited or absorbed onto surfaces through the intervention of precipitation
zooplankton:	plankton consisting of animals, such as protozoans

CHEMICAL SYMBOLS

Ag - silver

Al - aluminum

As - arsenic

Ca - calcium

Co - cobalt

Cu - copper

Fe - iron

H^+ - hydrogen ion

Mg - magnesium

Mn - manganese

Ni - nickel

Pb - lead

Se - selenium

SO_2 - sulphur dioxide

SO_4^{-2} - sulphate

V - vanadium

Zn - zinc

ABBREVIATIONS

CCM - copper circuit modification

CSI - calcite saturation index

EPA - Environmental Protection Act

IORP - Iron Ore Recovery Plant

IRRA - Inco's roast/reduction smelting alternative

kg ha^{-1}·yr^{-1} - kilograms per hectare year

meq 1^{-1} - milliequivalent per liter

NPV - net present value

NRWGT - non-regenrative weak gas treatment

OFF - Outokumpu flash furnace smelting

OHSA - Occupational Health and Safety Act

PIF - potentially injurious fumigation

ppm - part(s) per million

RRS - roast/reduction smelting

RWGT - regenerative weak gas treatment

SES - Sudbury Environmental study

TIA - Total Inflection Point Alkalinity

tpd - tons per day

TWA - time-weighted average

TWAEC - time-weighted average exposure criteria

ug - microgram

ug 1^{-1} - microgram per liter

ug m^{-3} - microgram per cubic meter